ALBERTA SOIL AND WATER QUALITY GUIDELINES FOR HYDROCARBONS AT UPSTREAM OIL AND GAS FACILITIES

VOLUME 1: PROTOCOL

September 2001

DRAFT

Pub. No: T/620
ISBN: 0-7785-1895-7 Printed Edition
ISBN: 0-7785-1898-1 On-line Edition
Web Site: http://www.gov.ab.ca/env/

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Land Branch
Science and Standards Division
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-5883
Fax: (780) 422-4192

or by e-mail to : Ted.Nason@gov.ab.ca

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1 Approach 1
1.2 Guideline Overview and Document Layout 1

2. TECHNICAL FRAMEWORK 2
2.1 Types of Site Closure 2
2.2 Levels of Site-Specific Information 3
2.2.1 Tier 1 - Generic Guidelines 3
2.2.2 Tier 2 - Modified Generic Guidelines 4
2.2.3 Tier 3 - Site-Specific Risk Assessment 4
2.3 Soil Type 4
2.4 Depth to Contamination 4
2.5 Land Use 4
2.6 Chemicals of Concern 5
2.7 Pathways 5
2.7.1 Human Health – Pathways Included 5
2.7.2 Human Health – Pathways Excluded 6
2.7.3 Ecological – Pathways Included 6
2.7.4 Ecological – Pathways Excluded 7
2.8 Receptors 8
2.8.1 Human 8
2.8.2 Ecological 8

3. HUMAN HEALTH SOIL GUIDEL[illegible] 9
3.1 Human Exposure [illegible] 9
3.2 Soil Ingestion 9
3.3 Soil Dermal Con[illegible]t 10
3.4 Indoor Vapour In[illegible]lat[illegible] 11
3.4.1 Calcul[illegible] α - General Considerations 12
3.4.2 Calcul[illegible]on of α for Coarse Soils 12
3.4.3 Calculation of α for Fine Soils 14
3.4.4 Calculation of α Using Site-Specific Soil Properties 14
3.5 Protection of Potable Groundwater 15
3.6 Example Calculation for Carcinogenic Chemicals 17

4. ECOLOGICAL HEALTH SOIL GUIDELINES 18
4.1 General Considerations 18
4.2 Ecological Exposure Limits 18
4.3 Plant/Invertebrate Soil Contact 19

DRAFT

4.4 Soil Ingestion (Livestock/Wildlife) 19
4.5 Protection of Groundwater – Ecological Receptors 20
4.5.1 General Considerations 20
4.5.2 Model Overview 20
4.5.3 Model Assumptions 21
4.5.4 Dilution Factor 1 22
4.5.5 Dilution Factor 2 22
4.5.6 Dilution Factor 3 23
4.5.7 Dilution Factor 4 24

5. SOIL TEXTURE AND DEPTH 26
5.1 General 26
5.2 Soil Texture 26
5.2.1 Human Health Pathways 26
5.2.2 Ecological Health Pathways 27
5.3 Soil Depth 27
5.3.1 Human Health Pathways 27
5.3.2 Ecological Health Pathways 27

6. WATER QUALITY GUIDELINES 28
6.1 Exposure Point Water Quality Guidelines 28
6.2 Groundwater Quality Guidelines 29
6.2.1 Human Drinking Water 29
6.2.2 Livestock Watering 29
6.2.3 Freshwater Aquatic Life and Wildlife Watering 29

7. REFERENCES 31

DRAFT

LIST OF TABLES

Table 2.1 Generic Soil Properties
Table 2.2 Chemicals of Concern
Table 2.3 Summary of Pathways
Table 2.4 Human Receptor Parameters
Table 2.5 Ecological Receptor Parameters
Table 3.1 Parameters for Indoor Air Inhalation Model
Table 3.2 Parameters for Protection of Potable Groundwater Model
Table 4.1 Parameters for Protection of Groundwater Model – Ecological Receptors

1. INTRODUCTION

The operation of upstream oil and gas facilities can result in the release of hydrocarbon compounds to the environment. This can be a concern either during the operation of the facility, or after decommissioning when land is returned to its former or a new use. Site closure is a term often used to describe regulatory acceptance that decommissioning is complete, and the land is ready to revert to its former or a new use. The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* were developed to assist in environmental management and site closure of upstream oil and gas facilities in Alberta.

The upstream sector of the oil and gas industry includes activities associated with the extraction of oil and gas from the subsurface up to the point it reaches the refinery. Examples of upstream oil and gas facilities include well sites and gas plants. Refineries and facilities for the distribution and sale of refined products are not part of the upstream sector. The *Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Facilities* specifically addresses releases of hydrocarbon mixtures from the upstream sector.

1.1 Approach

The approach taken in the development of these Guidelines follows the most recent regulatory guidance on management of upstream oil and gas sites (AENV 2000a), and on risk management at contaminated sites in Alberta (AENV, 2000b). Technically, the Protocol uses the Canada-Wide Standard for Petroleum Hydrocarbons in Soil (CCME, 2000) as a starting point, with adaptations to Alberta conditions where appropriate. The approach in CCME (2000) was itself based on, and developed from, previous methodology developed by the CCME (1996).

DRAFT

1.2 Guideline Overview and Document Layout

The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* are presented in three volumes:

Volume 1	Protocol
Volume 2	Guideline Development
Volume 3	Guideline Summary and User Guidance

Volume 1 (this volume) includes an overview of the project, provides background and rationale for the approach used, and develops the technical protocol used for guideline development. Volume 2 provides details of the guideline development process, including all chemical-specific information. Volume 3 summarizes guideline values, and provides user guidance. Volume 3 provides all the

information required by users of generic guidelines. Users wishing to develop modified generic guidelines or site-specific remediation objectives will find useful information in all 3 volumes.

The remainder of the current document (Volume 1) is organized as follows: Section 2 provides the technical framework for the guidelines, and describes in detail *which* guidelines were developed. Sections 3 and 4 describe *how* the soil guidelines were developed for human health and ecological pathways, respectively, including formulae and non chemical-specific parameters. Section 5 includes information on how the guidelines developed in Sections 3 and 4 were adapted to apply to different soil textures and to subsoil. Section 6 addresses guidelines for groundwater quality.

Volume 3 is the critical document for the application of these guidelines. Certain procedures and conditions described below have limited application as described in Volume 3.

2. TECHNICAL FRAMEWORK

The technical framework describes the format for the *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* and their application. The Guidelines:

1. provide a sound scientific basis for the management of petroleum hydrocarbon contamination at upstream oil and gas sites;
2. are consistent with Alberta Environment policy for managing such sites; and,
3. draw on and develop the work done for the Canada-Wide Standard f[illegible]eum Hydrocarbons (CCME, 2000) in so far as it is applicable to upstream oil and g[illegible]erta.

Key concepts are discussed below.

DRAFT

2.1 Types of Site Closure

In the document "*A Proposed Ma[illegible]k and Associated Remediation Objectives for Upstream Oil and Gas Sit[illegible]*" AENV (2000a) defines three potential closure conditions for Upstream Oil and Ga[illegible]n Alberta:

- Unconditional Closure;
- Conditional Closure; and,
- Deferred Closure.

Two of these - Unconditional Closure and Conditional Closure – are key concepts in the scope of this document and are described below.

Unconditional Closure implies that all normal activities that could occur under the land use designation are protected, (*i.e.*, land use is not restricted). Sites may be eligible for Unconditional Closure either i) by being "screened out" from further consideration after a rigorous Phase 1 assessment, ii) after analytical testing that shows compliance with the Unconditional Closure guidelines for soil and groundwater, or iii) after remediation and confirmatory analyses that show compliance with the Unconditional Closure guidelines for soil and groundwater (AENV, 2000a). This document provides the Protocol for developing guidelines for Unconditional Closure.

Conditional Closure is an option that may be available when technical or economic considerations make Unconditional Closure impractical. Conditional Closure is intended to be used at sites where certain restrictions on the land use are required to ensure that human and ecological health are protected. Conditional closure will normally involve institutional or engineered controls (*e.g.*, a restriction on groundwater usage) to manage risks until Unconditional Closure guidelines are met. Landowner participation will be a crucial element of any risk management plan involving Conditional Closure. In addition, certain technical and policy conditions (*e.g.*, removal of free phase hydrocarbons, characterization of the extent and stability of the groundwater plume, salinity of the groundwater) must be met for Conditional Closure to be an acceptable option. These issues are discussed more fully in the user guidance in Volume 3.

2.2 Levels of Site-Specific Information

The technical framework allows for three Tiers, corresponding to three levels of site-specific information:

- Tier 1 or generic guidelines;
- Tier 2 or modified generic, guidelines; and,
- Tier 3 or site-specific remediation objectives developed through risk assessment.

The level of protection on which all guidelines are based

DRAFT

2.2.1 Tier 1 - Generic Guidelines

This document provides the Protocol for generating generic guidelines. These guidelines are based on a set of parameters which allow reasonably conservative predictions of risk at most upstream oil and gas sites throughout Alberta. Tier 1 guidelines will be applicable to the majority of upstream hydrocarbon sites in Alberta. A few sites will have conditions that result in higher contaminant exposures than was assumed for the generic scenarios (*e.g.*, sites underlain by very coarse materials such as gravels). In such cases, Tier 1 guidelines will not apply, and a Tier 2 or Tier 3 approach will be required.

2.2.2 Tier 2 - Modified Generic Guidelines

There may be circumstances where, based on the conditions at a particular site, the generic guidelines are unnecessarily conservative. Or, as outlined above for certain sites, assumptions used for guideline development may be too liberal; triggering a Tier 2 or 3 approach. Accordingly, guidance is provided in Volume 3 on ways in which the generic guidelines can be modified for use at a particular site, including a discussion of parameters for which generic values could be replaced by site-specific values. Guidance is also provided on the information that would be required to demonstrate that such site-specific values were applicable at a given site.

2.2.3 Tier 3 - Site-Specific Risk Assessment

Large or complex sites may require a site-specific risk assessment and/or toxicity testing to develop appropriate remediation objectives. There is much regulatory guidance available to assist with this process, but such work is outside the scope of the present document.

2.3 Soil Type

Generic guidelines were derived for two soil types, Coarse Soil and Fine Soil. These soils are defined as having a median grain size greater or less than 75 microns, respectively. This definition is consistent both with previous work conducted in Alberta (*e.g.*, AEP, 1994b) and the Canada-Wide Standard. Assumed properties for these two standard soils are taken from CCME (2000) and are summarized in Table 2.1.

DRAFT

2.4 Depth to Contamination

Separate guidelines were developed for surface soil and subsoil. The rationale for this was that: i) some of the direct contact pathways apply to surface soils only and ii) for some pathways (*e.g.*, ecological soil contact, indoor vapour inhalation) different guidelines may be appropriate in subsoil to achieve the same level of protection as that defined for surface soil. For consistency with CCME (2000), the split between surface soils and subsoil was at 1.5 m depth. A discussion of how surface soil guidelines are adapted to be applicable to subsoils is included in Section 5.3.

2.5 Land Use

Previous work developing soil quality guidelines in Canada (*e.g.*, CCME, 1996, 1997, and 2000) has focussed on four main land use types: agricultural, residential/parkland, commercial, and industrial. This document provides a Protocol for developing guidelines for these four land uses, and also a fifth land use. The "natural area" land use was defined as an area where permanent human occupation is not anticipated, and only occasional human presence is likely. Typically, natural area land use will be

applied to the forested parts of Alberta away from human habitation, and will correspond approximately to the "Green Area" of the Province. The other four land uses are as defined in CCME (2000).

2.6 Chemicals of Concern

The scope of work defined the chemicals of concern to include petroleum hydrocarbons. This project takes the work done by CCME (2000) in which guidelines were generated for four PHC fractions (F1, F2, F3 and F4), and expands the scope to include BTEX components as individual chemicals, and carcinogenic PAHs quantified as equivalent benzo(a)pyrene (BaP). Note that at many sites, significant concentrations of carcinogenic PAHs will not be expected based on the composition of the original petroleum hydrocarbon release. In such cases, analysis for carcinogenic PAH compounds will not be required. Volume 3 includes guidance on when PAH analysis is required, and how the concentrations of carcinogenic PAHs should be calculated as equivalent concentrations of benzo[a]pyrene (B(a)P). The four PHC fractions are defined by CCME (2000) in terms of an equivalent carbon number range, with BTEX and carcinogens specifically excluded and removed from the appropriate fraction under consideration. The chemicals of concern, including the equivalent carbon number ranges of the four fractions are summarized in Table 2.2.

The chemicals of concern in this project therefore include all petroleum hydrocarbons except for polar compounds. Polar compounds are hydrocarbons that include oxygen, nitrogen, and/or sulphur atoms, and are excluded from the scope of this project.

2.7 Pathways

There are a wide range of pathways by which chemicals of concern may reach human and ecological receptors. The pathways considered by this project are adapted from CCME (2000). Table 2.3 summarizes which pathways are considered for [illegible] and soil. The rationale for including or excluding each pathway in the present document is discussed below.

DRAFT

2.7.1 Human Health – Pathways Included

The following four pathways are the same four human health pathways considered by CCME (2000). All four human health pathways are calculated for all land uses except that only the protection of potable groundwater is considered in natural areas.

- ***Soil Ingestion*** was included to account for small amounts of soil inadvertently consumed by humans. Applies to all land uses except natural areas (human exposure in natural areas is expected to be low).

- ***Soil Dermal Contact*** was included to account for absorption of chemicals of concern from soil adhering to exposed skin. Applies to all land uses except natural areas (human exposure in natural areas is expected to be low).

- ***Indoor Vapour Infiltration*** was included to account for exposure to volatile chemicals of concern being drawn into residences or workplaces from contaminated soil and groundwater. This pathway was calculated for agricultural, residential, commercial, and industrial land uses, but not for natural areas (buildings generally not present).

- ***Protection of Potable Groundwater*** was included to account for exposure to chemicals of concern in drinking water sourced from water wells, and applies to all land uses.

2.7.2 Human Health – Pathways Excluded

Certain pathways were considered in CCME (1996), but were not included in CCME (2000) and are not included in the present work. Brief reasons why each pathway was excluded from the guideline derivation process are provided below.

- ***Ingestion/Dermal Contact With Surface Water*** (*i.e.*, drinking or swimming in surface water fed by either contaminated groundwater or contaminated runoff). This pathway was not considered because it was expected to be a less sensitive pathway than ingestion of groundwater (from water wells) due to the dilution that will normally occur when contaminated groundwater discharges to a surface water body, and a generally low frequency of exposure.

- ***Dust Inhalation***. Experience from conducting risk assess[illegible]ious areas of Alberta suggests that, for hydrocarbons, this pathway is usually insig[illegible]cant com[illegible]red to other pathways such as soil ingestion, ingestion of potable groundwater, inh[illegible] of in[illegible]or air.

- ***Inhalation of Outdoor Air***. This pathw[illegible] is [illegible] ex[illegible]c[illegible] to[illegible] significant when compared to the inhalation of outdoor air, bas[illegible] he[illegible] am[illegible]d[illegible]ion that occurs when a flux of contaminated vapour from an u[illegible]erg[illegible]no[illegible]o[illegible] m[illegible]es with outdoor air.

- ***Ingestion of Milk, Meat/Gar[illegible] P[illegible]du[illegible] and Fish***. Any of these pathways may be significant for compounds that tend to b[illegible]centrate into animal or plant matter. However, petroleum hydrocarbons do not tend to biomagnify through food webs (Suter, 1997), and so it is not anticipated that these pathways will be significant.

DRAFT

2.7.3 Ecological – Pathways Included

The following pathways for protection of ecological health are included. These are the same as the pathways considered by CCME (2000) with two exceptions: i) nutrient cycling was excluded for the

reasons provided in the following section, and ii) only soil ingestion, rather than soil and food ingestion, was considered for livestock and wildlife, as discussed below.

- ***Plant/Invertebrate Soil Contact.*** Plants form the base of the food web and invertebrates are essential to soil structure and function. Healthy plant and invertebrate life are central to soil quality. This pathway was calculated for all land uses.

- ***Soil Ingestion by Livestock/Wildlife.*** CCME (2000) includes a soil and food ingestion pathway for livestock. However, sufficient information on bioconcentration of hydrocarbons into food is not currently available, and this pathway was not calculated for any of the hydrocarbon fractions in CCME (2000). Hydrocarbons do not tend to bioconcentrate into plants (Suter, 1997). Therefore, for both scientific and pragmatic reasons, in the current work, exposure to contaminants in ingested soil, but not ingested food, was considered. This pathway was calculated for agricultural and natural areas land use only.

- ***Protection of Groundwater for Aquatic Life.*** Dissolved phase contaminants may be transported in groundwater to surface water bodies (*e.g.*, creeks, wetlands, lakes, etc.) where adverse effects on freshwater aquatic life are possible. This pathway need only be considered when there is a surface water body within 300m downgradient of the source of contamination. Downgradient is considered to be any direction within 45 degrees either side of the calculated mean direction of groundwater flow. The distance of 300 m was selected as being greater than the length of the vast majority of groundwater plumes of dissolved hydrocarbon. This value is based on preliminary results from studies of hydrocarbon plumes in the upstream oil and gas industry in Western Canada currently being undertaken by the CORONA group (Consortium of Research on Natural Attenuation). The value of 300 m is also consistent with a compilation of 647 petroleum hydrocarbon plumes presented in Wiedemeier *et al.* (1999), in which it was determined that 98.1% of the plumes were less than 900 feet (274 m) long. This pathway was calculated for all land uses.

- ***Protection of Groundwater for Livestock and Wildlife Watering.*** Dissolved phase contaminants may be transported in groundwater to surface water or natural surface water bodies (dugouts, creeks, wetlands, lakes, etc.) where livestock or wildlife may drink from them and be exposed to contaminants. This pathway was calculated for natural areas and agricultural land use only.

DRAFT

2.7.4 Ecological – Pathways Excluded

The following pathways were included (but not calculated) in CCME (2000). They are excluded from the current work for the reasons given below.

- ***Ingestion of Plant Material by Livestock or Wildlife.*** As noted in the preceding section, this pathway was not included because petroleum hydrocarbons do not tend to bioconcentrate into plants (Suter, 1997).

- ***Nutrient Cycling*** by soil microbes is one of the vital processes in any healthy soil. Accordingly, the effect of contaminated soil on microbe nutrient cycling needs to be considered. Available data for this pathway are summarized in Volume 2. In all cases, the data are insufficient (by CCME, 1996 protocols) to calculate this guideline.

2.8 Receptors

2.8.1 Human

Humans are present in four out of the five land use scenarios – humans are not included in the natural area scenario due to an anticipated low exposure frequency. Note, however, that humans *are* considered in the protection of potable groundwater pathway for natural areas, based on the AENV (2001) definition of a domestic use aquifer. Human receptor parameters are summarized in Table 2.4.

Different approaches were taken towards selecting receptors for carcinogenic and non-carcinogenic chemicals of concern. For non-carcinogens, the most sensitive human life-stage for each land use was selected as being the critical receptor. The critical receptor for agricultural, residential, and commercial land use is a toddler (CCME, 2000). For industrial land use it is assumed that children do not have regular access, and the critical receptor is assumed to be an adult worker (CCME, 2000).

Potential adverse effects from carcinogens are cumulative over a lifetime, and so exposure duration is a major factor in determining the most sensitive receptor. Following guidance from CCME (1996), exposures to carcinogens were assessed by considering an adult exposed for a full lifetime. Guidelines were calculated at an incremental cancer risk of 10^{-5}.

DRAFT

2.8.2 Ecological

For the ecological soil contact and soil vapour inhalation pathways, the approach taken was to protect a generic ecological receptor. For the soil ingestion pathway and for the protection of groundwater for livestock and wildlife watering pathways, a specific receptor was selected to represent each land use. A dairy cow was used for agricultural land use and a mule deer for natural areas. Ecological receptor parameters are summarized in Table 2.5.

3. HUMAN HEALTH SOIL GUIDELINES

This section describes the general approach taken to derive human toxicological exposure limits, and then considers each of the human health pathways identified in Section 2.7.1. For each of these pathways, the equations used to calculate the guideline are those used in CCME (2000). Detailed explanations of the equations and parameters used are available in that document and are not reproduced here. Rather, the equations and parameters to be used are summarized, and places where the methodology or parameters used in this document differ from those used in CCME (2000) are emphasized.

Where appropriate, a brief description is provided of the transport processes that underlie the calculation of each guideline. This is followed by the equation that is used to calculate the guideline. Beneath each equation, the parameters are described, and the units specified. For non chemical-specific parameters, either a value is provided, or reference made to one of the Tables in this report. Values for chemical-specific parameters are provided in the guideline development work (Volume 2).

Note that the equations in this document follow standard mathematical convention in that multiplication is indicated by two parameters being adjacent with no operator symbol between them. Where this convention might be ambiguous, the multiplication operator (×) is used explicitly.

3.1 Human Exposure Limits

Each of the human health based guidelines calculated in the following sections is based on a human exposure limit, which reflects the concentration or dose of a chemical of c[illegible]hat is considered unlikely to cause adverse health effects in sensitive humans. These exp[illegible]li[illegible]re chemical-specific values, and as such are included in the guideline development work (V[illegible]lume 2). [illegible]owever, the general approach is to use regulatory-approved limits where available[illegible]he f[illegible]ng or[illegible] of preference:

- Health Canada;
- exposure limits used in the PHC [illegible]W[illegible]nda[illegible]E[illegible]000); and,
- United States Environmental Prot[illegible]ion[illegible]ge[illegible]y [illegible]S [illegible]tabase (US EPA, 2001).

Exposure limits for carcinogens are ex[illegible]es[illegible] at[illegible] incremental cancer risk of 10^{-5}.

DRAFT

3.2 Soil Ingestion

The soil quality guideline for soil ingestion (SQG_{SI}) was calculated in the same way as CCME (2000). The following equation is used:

$$SQG_{SI} = \frac{(TDI - EDI) \times SAF \times BW \times 10^3}{SIR \times AF_G \times ET} + [BSC]$$

where:

SQG_{SI}	=	human health soil quality guideline for soil ingestion (mg/kg);
TDI	=	tolerable daily intake (mg/kg-day; chemical-specific parameter);
EDI	=	estimated daily intake (mg/kg-day; chemical-specific parameter);
SAF	=	soil allocation factor (dimensionless; chemical-specific parameter);
BW	=	body weight (kg; see Table 2.4);
10^3	=	conversion factor from kg to g;
SIR	=	soil ingestion rate (g/day; see Table 2.4;);
AF_G	=	absorption factor for gut (dimensionless; chemical-specific parameter);
ET	=	exposure term (dimensionless; see Table 2.4); and,
BSC	=	background soil concentration (mg/kg; chemical-specific parameter).

3.3 Soil Dermal Contact

The soil quality guideline for soil dermal contact (SQG_{DC}) was calculated in the same way as CCME (2000). The total loading of soil on the body was calculated as the product of exposed skin surface area and dermal loading, and was calculated separately for hands and other skin surfaces. The amount of chemical that gains access to the body following each dermal exposure event was calculated by multiplying the loading of chemical on the skin (*i.e.*, soil loading multiplied by soil concentration) by a dermal absorption factor. The following equation is used:

$$SQG_{DC} = \frac{(TDI - EDI) \times SAF \times BW \times 10^6}{AF_D \times \{(SA_{HANDS} \times DL_{HANDS}) + (SA_{OTHER} \times DL_{OTHER} \times EF \times$$ + $[BSC]$

DRAFT

where:

SQG_{DC}	=	human health soil dermal guideline for soil dermal contact (mg/kg);
TDI	=	tolerable daily intake (mg/kg-day; chemical-specific parameter);
EDI	=	estimated daily intake (mg/kg-day; chemical-specific parameter);
SAF	=	soil allocation factor (dimensionless; chemical-specific parameter);
BW	=	body weight (kg; see Table 2.4);
10^6	=	conversion factor from kg to mg;
AFD	=	absorption factor for dermal (dimensionless; chemical-specific parameter);
SA_{hands}	=	hand surface area (cm^2; see Table 2.4);
DL_{hands}	=	dermal soil loading for hands (mg/cm^2-event; see Table 2.4);
SA_{other}	=	surface area for other exposed skin (cm^2; see Table 2.4);
DL_{other}	=	dermal soil loading for other exposed skin (mg/cm^2-event; see Table 2.4);

EF = exposure frequency (events/day; see Table 2.4)
ET = exposure term (dimensionless; see Table 2.4); and,
BSC = background soil concentration (mg/kg; chemical-specific parameter).

3.4 Indoor Vapour Inhalation

The approach taken to calculate the guideline for this pathway is identical to that used in CCME (2000). Essentially, three processes are considered:

1. three-phase partitioning to predict the concentration of a contaminant in soil vapour from the measured concentration of that contaminant in soil;
2. a dilution factor to predict indoor air concentrations from soil vapour concentrations; and,
3. a standard exposure equation to predict exposure dose from indoor air concentration.

These three processes are combined in the following equation for the indoor vapour inhalation guideline:

$$SQG_{II} = \frac{(RfC - C_a)\times[\theta_w + (K_{oc}\times f_{oc}\times \rho_b) + ((H/RT)\times\theta_a)]\times SAF\times DF_i\times 10^3}{(H/RT)\times\rho_b\times ET\times 10^6} + BSC$$

where:

SQG_{II} = soil quality guideline for indoor infiltration (mg/kg);
RfC = reference air concentration (mg/m^3; chemical specific parameter);
C_a = background indoor air concentration (mg/m^3; chemical specific parameter);
θ_w = moisture-filled porosity (dimensionless; see Table 2.1);
K_{oc} = organic carbon partition coefficient (mL/g; chemical specific parameter);
f_{oc} = fraction organic carbon (g/g; see Table 2.1);
ρb = dry bulk density (g/cm^3; see Table 2.1);
H = Henry's Law Constant (atm-m^3/mol; chemical specific parameter);
R = gas constant (8.205 × 10^{-5} atm-m^3/mol-°K);
T = soil temperature (°K; see Table 2.1);
θ_a = vapour-filled porosity (dimensionless; see Table 2.1);
SAF = soil absorption factor (dimensionless; chemical-specific parameter);
DF_i = dilution factor from soil gas to indoor air (dimensionless; see derivation below);
10^3 = conversion factor from kg to g;
ET = exposure term (dimensionless; see Table 2.4);
10^6 = conversion factor from m^3 to cm^3; and,
BSC = background soil concentration (mg/kg; chemical specific parameter).

DRAFT

Definition of Attenuation Coefficient (α)

The attenuation coefficient (α) is defined as the inverse of the dilution factor. Accordingly, the dilution factor may be calculated as:

$$DF_I = \frac{1}{\alpha}$$

where:

DF_I	=	dilution factor from soil gas concentration to indoor air concentration (dimensionless); and,
α	=	attenuation coefficient (dimensionless; derived below)
	=	(contaminant vapour concentration in the building)/(vapour concentration at the contaminant source).

3.4.1 Calculation of α - General Considerations

Calculation of the attenuation coefficient (α) is a critical step in the derivation of this guideline. The approach used is based on work by Johnson and Ettinger (1991), who consider two vapour transport processes:

1. far from the building foundation, diffusive transport of volatile contaminants in the soil is assumed to be the dominant vapour transport mechanism; and,
2. close to the building foundation, it is assumed that advective transport towards and through floor cracks, driven by the pressure differential between ambient conditions and the inside of a building, will be the dominant mechanism.

They derive an equation for α in the general case where both these processes are significant. However, following the approach taken in CCME (2000), the limiting case of the equation considering advection only is used for coarse soils, and the limiting case considering diffusion only is used for fine soils. For modified generic or site-specific guidelines the full equation, considering both advection and diffusion is used.

DRAFT

3.4.2 Calculation of α for Coarse Soil

As noted above, the attenuation coefficient for coarse soils was calculated using the limiting case of the Johnson and Ettinger (1991) equation for cases where only advective transport is significant:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right)}{\left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right) + 1}$$

where:

α	=	attenuation coefficient (dimensionless);
D_T^{eff}	=	effective porous media diffusion coefficient (cm^2/s; derived below);
A_B	=	building area (cm^2; see Table 3.1);
Q_B	=	building ventilation rate (cm^3/s; derived below);
L_T	=	distance from contaminant source to foundation (cm; see Table 3.1); and,
Q_{soil}	=	volumetric flow rate of soil gas into the building (cm^3/s; derived below).

Calculation of D_T^{eff}:

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2} \right)$$

where:

D_T^{eff}	=	overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm^2/s);
D_a	=	diffusion coefficient in air (cm^2/s; chemical specific parameter);
θ_a	=	vapour-filled porosity (dimensionless; see Table 2.1); and,
θ_t	=	total soil porosity (dimensionless; see Table 2.1).

Calculation of Q_B:

$$Q_B = \frac{L_B \times W_B \times H_B \times ACH}{3{,}600}$$

DRAFT

where:

Q_B	=	buildi[illegible] (cm^3
L_B	=	buildi[illegible] (see Table 3.1);
W_B	=	buildi[illegible] (see Table 3.1);
H_B	=	buildi[illegible], including basement (cm; see Table 3.1);
ACH	=	air ex[illegible]s per hour (h^{-1}; see Table 3.1); and,
3,600	=	conve[illegible]on factor from hours to seconds.

Calculation of Q_{soil}:

$$Q_{soil} = \frac{2 \times \pi \times \Delta P \times k_v \times X_{crack}}{\mu \times ln\left[\frac{2 \times (Z_{crack})}{r_{crack}} \right]}$$

where:

Q_{soil}	=	volumetric flow rate of soil gas into the building (cm^3/s);
ΔP	=	pressure differential ($g/cm \cdot s^2$; see Table 3.1);
k_v	=	soil permeability to vapour flow (cm^2; see Table 2.1);
X_{crack}	=	length of idealized cylinder (cm; see Table 3.1);
μ	=	vapour viscosity (g/cm·s; chemical specific parameter);
Z_{crack}	=	distance below grade to idealized cylinder (cm; see Table 3.1); and,
r_{crack}	=	radius of idealized cylinder (cm; see Table 3.1).

3.4.3 Calculation of α for Fine Soils

As noted above, the attenuation coefficient for fine soils was calculated using the limiting case of the Johnson and Ettinger (1991) equation for cases where only diffusive transport is significant:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right)}{1 + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B L_{crack}}{D_{crack} A_{crack} L_T}\right)}$$

where:

α	=	attenuation coefficient (dimensionless);
D_T^{eff}	=	effective porous media diffusion coefficient (cm^2/s; see *);
A_B	=	building area (cm^2; Table 3.1);
Q_B	=	building ventilation rate (cm^3/s; see *);
L_T	=	distance from contaminant source to foundation (crack; Table 3.1);
L_{crack}	=	thickness of the foundation (crack; Table 3.1);
D_{crack}	=	effective vapour-phase diffusion coefficient through the crack (cm^2/s; Table 3.1); and,
A_{crack}	=	area of crack through which contaminant vapours enter building (cm^2; Table 3.1).

* The parameters D_T^{eff} and Q_B were calculated using the same equations as for coarse soil (see Section 3.4.2 above).

DRAFT

3.4.4 Calculation of α Using Site-Specific Soil Properties

Modified generic guidelines (Tier 2) or site-specific guidelines (Tier 3) may be calculated for this pathway using the above approach by substituting site-specific values for one or more of the parameters in the equations. Guidance is provided in Volume 3 (User Guidance) as to which parameters may be

changed at Tier 2, and what information is required to justify using site-specific parameters. For Tier 2 and Tier 3 calculations, the full Johnson and Ettinger (1991) equation for α should be used:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right)}{exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]}$$

where:

α	=	attenuation coefficient (dimensionless);
D_T^{eff}	=	effective porous media diffusion coefficient (cm^2/s; see *);
A_B	=	building area (cm^2; Table 3.1);
Q_B	=	building ventilation rate (cm^3/s; see *);
L_T	=	distance from contaminant source to foundation (cm; Table 3.1);
Q_{soil}	=	volumetric flow rate of soil gas into the building (cm^3/s; see *);
L_{crack}	=	thickness of the foundation (cm; Table 3.1);
D_{crack}	=	effective vapour diffusion coefficient through the crack (cm^2/s; Table 3.1); and,
A_{crack}	=	area of cracks through which contaminant vapours enter the building (cm^2; Table 3.1).

The parameters D_T^{eff}, Q_B, and Q_{soil} were calculated using the same equations as for coarse soil (see Section 3.4.2 above).

DRAFT

3.5 Protection of Potable Groundwater

The guideline for protection of potable groundwater (SQG$_{GW}$) was calculated in the same way as CCME (2000), though different parameters are used in calculating the dilution factors for coarse and fine soil. The basis of the calculation is the soil organic carbon partition coefficient ($K_{oc}f_{oc}$) and soil moisture content were used to link the measured soil concentration with the pore water concentration. Next a dilution factor was calculated, linking concentrations in soil pore water adjacent to the source to concentrations in groundwater immediately below. This calculation is based on recharge rate, site length, and aquifer parameters, and is used to link pore water concentrations to "reasonable worst case" groundwater concentrations. Thus a conservative relationship between measured soil concentration and groundwater concentration is established. The following equation is used:

$$SQG_{GW} = \frac{(TDI - EDI) \times ((K_{oc} \times f_{oc}) + (\theta_m / \rho_w)) \times BW \times DF_W}{IR_W} + BSC$$

where:

SQG_{GW}	=	soil quality guideline for protection of potable groundwater (mg/kg);
TDI	=	tolerable daily intake (mg/kg-day; chemical-specific parameter);
EDI	=	estimated daily intake (mg/kg-day; chemical-specific parameter);
K_{oc}	=	organic carbon partition coefficient (mL/g; chemical specific parameter);
f_{oc}	=	fraction organic carbon (g/g; see Table 2.1);
θ_m	=	ratio of mass of water in soil/dry mass of soil (g/g; see Table 2.1);
ρ_w	=	density of water (g/cm^3; see Table 3.2);
BW	=	body weight (kg; see Table 2.4);
DF_W	=	groundwater/pore water dilution factor (dimensionless; calculated below);
IR_W	=	ingestion rate of water (L/day; see Table 2.4); and,
BSC	=	background soil concentration (mg/kg; chemical-specific parameter).

Not that a soil allocation factor was not included in the equation for this pathway consistent with CCME (2000).

The dilution factor was calculated as follows:

$$DF_w = \frac{B \times K \times i}{I \times L} + 1$$

where:

DF_W	=	groundwater/pore water dilution factor (dimensionless);
B	=	effective mixing depth in aquifer (m; see Table 3.2);
K	=	saturated hydraulic conductivity of aquifer (m/y; see Table 2.1);
i	=	hydraulic gradient (dimensionless; see Table 3.2);
I	=	recharge rate (m/y; see Table 2.1); and,
L	=	site length (m; see Table 3.2).

The calculation of the protection of potable groundwater guideline in this document differs from the approach used in CCME (2000) only in the value of the parameter. Groundwater recharge (Table 3.2) is set to Alberta-specific values of 60 mm/year and 12 mm/year for coarse and fine soil, respectively.

DRAFT

These values are based on extensive research by Atomic Energy of Canada Limited (AECL, 1990, 1991, 1992, and 1995) and hydrogeological literature for the prairies (*e.g.*, Trudell, 1994; Keller *et al.*, 1986; Woo and Rowsell, 1993). This work is consistent with groundwater recharge being less than 10% of precipitation in Coarse soils and less than 2% of precipitation in Fine soils. Taking these values together with precipitation data for the wettest of the Alberta locations for which climate normals are available (Edson: precipitation = 568 mm/year, based on 1961 to 1990 Canadian Climate Normals, Environment Canada, 2001) and rounding up, gives recharge values of 60 mm/year, and 12 mm/year for Coarse and Fine soils, respectively.

Note that, consistent with CCME (2000), the value for the saturated hydraulic conductivity of Fine soils (Table 2.1) was 32 m/year, reflecting the fact that aquifers with saturated hydraulic conductivities less than this are unlikely to provide sufficient yield to supply the drinking water for a residence.

Note also that the mixing depth, B, is assumed to be 2 m (CCME, 2000). This value is based on the typical minimum screened length for a domestic water well, due to the mixing of water that will occur within the screened interval. No such mixing typically occurs when groundwater is discharged at a spring or creek, and accordingly the mixing depth for the ecological protection of groundwater pathways is smaller (Section 4.5.6).

3.6 Example Calculation for Carcinogenic Chemicals

Guidelines for carcinogenic chemicals (benzene and B(a)P) are calculated in a similar way to those for non-carcinogenic chemicals with the following differences:

- the risk-specific concentration (RsC), evaluated at an excess cancer risk of 1 in 100,000, is used in place of the reference concentration (RfC);
- the risk-specific dose (RsD), evaluated at an incremental cancer risk of 1 in 100,000, is used in place of the tolerable daily intake (TDI);
- background exposure is not considered, as guidelines are based on excess cancer risk above background;
- exposure to carcinogens is evaluated for lifetime exposure (CCME, 1996); and,
- adults, rather than toddlers, are used as the receptor of concern in all land uses.

The soil quality guidelines calculated for benzene for the soil ingestion [illegible]ay (SQG_{SI}) were calculated using the following equation:

$$SQG_{SI} = \frac{RsD \times B \times 10^3}{R \times AF_G \times [illegible]}$$

DRAFT

Where:

SQG_{SI}	=	human [illegible]eline for soil ingestion (mg/kg);
RsD	=	risk-s[illegible]os[illegible]evaluated at an excess cancer risk of 1 in 100,000 (mg/k[illegible]ay; chemical-specific parameter);
SAF	=	soil al[illegible]cation factor (dimensionless; chemical-specific parameter);
BW	=	adult body weight (kg; Table 2.4);
10^3	=	conversion factor from kg to g;
SIR	=	soil ingestion rate for the adult (g/day; Table 2.4;);
AF_G	=	absorption factor for gut (dimensionless; chemical-specific parameter); and,
ET	=	exposure term for residential use (dimensionless; Table 2.4).

4. ECOLOGICAL HEALTH SOIL GUIDELINES

4.1 General Considerations

The procedures for calculating guidelines for each of the pathways listed in Section 2.7.3 are detailed in the following sections. Some considerations that apply to all pathways are discussed below. Much of this section is based on protocols published in CCME (1996), and refined in CCME (2000). Where appropriate, reference is made to specific sections in these documents.

Regulatory exposure limits are generally not available for ecological endpoints, and accordingly exposure limits may have to be developed from available and applicable toxicological data. Exposure limits are developed in the guideline development work (Volume 2), using methods previously developed by the CCME (1996 and 2000), and adapted where appropriate. The main departures from the above-noted protocols involve increased emphasis on professional judgement in assessing the toxicological data. In particular, the emphasis in this document is on generating guidelines for pathways whenever it is scientifically justified to do so from the available toxicological dataset. The rationale for this is that it is normally easier to make sound management decisions for contaminated sites with some guideline for a particular pathway than with no guideline for that pathway.

In the sections which follow, reference is made to procedures published in CCME (1996, 2000). The relevant parts of these procedures are summarized in the following sections, but the reader is referred to the original documents for further detail and background information.

DRAFT

4.2 Ecological Exposure Limits

Three main groups of ecological receptors are considered, each with its own exposure limit:

1. The exposure limit for plants and soil invertebrates is expressed as a concentration in units of mg/kg and is adopted directly as the soil contact guideline. General principles used in calculating this guideline are discussed in Section 4.3. The derivation of the exposure limit and guideline for each chemical is provided in Volume 2.

2. The exposure limit for freshwater aquatic life is expressed as a concentration in units of mg/L and is adopted directly as the protection of groundwater for aquatic life guideline. The values for this exposure limit are adapted directly from CCME (1999) values where available, or are derived using CCME (1999) protocols. Details for each chemical are provided in Volume 2.

3. The exposure limit for mammalian (non-human) receptors is expressed as a dose in units of mg/kg-bw/day and is referred to as the daily threshold effect dose (DTED). The DTED is used to calculate the livestock/wildlife soil ingestion and the livestock/wildlife watering guidelines. The DTED for each chemical is calculated in Volume 2, and is based on either livestock or laboratory animal toxicological data depending on availability. An uncertainty factor is applied to the toxicological data to derive the DTED. The value of the uncertainty factor depends on the quality of the toxicological data and the scope of the experiment.

4.3 Plant/Invertebrate Soil Contact

The guideline for this pathway is derived from data collected specifically for this project, and is discussed in Volume 2.

4.4 Soil Ingestion (Livestock/Wildlife)

A protocol is provided to calculate a guideline for livestock/wildlife soil and food ingestion in Section B7.6 of CCME (1996). However insufficient toxicological or bioconcentration data exist to calculate this guideline for any of the chemicals of concern. Accordingly two modifications to this protocol are used in the present work:

1. Only soil ingestion is considered. Petroleum hydrocarbons do not tend to bioconcentrate into the food web (*e.g.*, Suter 1997). Accordingly it is anticipated that exposure by livestock and wildlife to chemicals of concern via food ingestion will be a minor pathway in comparison to soil ingestion.

2. A livestock/wildlife Daily Threshold Effect Dose (DTED) is developed for each chemical of concern by extrapolation from studies using laboratory animals using appropriate uncertainty factors. Uncertainty factors are selected using the same rationale used for developing human health exposure limits, and is discussed for each chemical in Volume 2.

DRAFT

A guideline for this pathway was calculated using a dairy cow for agricultural land use, and a mule deer for natural areas. Receptor parameters are summarized in Table 2.5. The following equation was used:

$$SQG_{ESI} = \frac{0.75 \times DTED \times BW \times 1{,}000}{SIR \times BF}$$

where:

SQG_{ESI} = ecological quality guideline for soil ingestion (mg/kg);
0.75 = factor to prevent animals from being exposed to more than 75% of the DTED (dimensionless; CCME, 1996);
DTED = daily threshold effect dose (mg/kg-day; chemical-specific parameter);

BW	=	body weight (kg; see Table 2.5);
1,000	=	conversion factor from kg to g;
SIR	=	soil ingestion rate (g/day; see Table 2.5); and,
BF	=	bioavailability factor (dimensionless; assumed to be 1.0).

4.5 Protection of Groundwater – Ecological Receptors

4.5.1 General Considerations

This pathway considers the allowable concentrations in soil that will not cause unacceptable concentrations in natural surface water bodies or dugouts for two groups of receptors: 1) freshwater aquatic life, and 2) livestock or mammalian wildlife species. The methodology used for protection of surface water quality follows CCME (2000), and differs from that used to calculate the protection of potable groundwater pathway in this document, and the methodology used for the protection of groundwater for aquatic life in CCME (1996) by introducing a minimum 10 m lateral offset between source and exposure point (*i.e.*, surface water body). The model and parameters used to relate the concentration of a contaminant in soil to that in a surface water body are discussed in the following sections. Parameters used in the model are summarized in Table 4.1. Dugouts are handled somewhat differently as described in Section 6.2.2.

The protection of groundwater for freshwater aquatic life applies [illegible]ses, and the guideline for each chemical of concern was derived from the water quality gu[illegible]ne for f[illegible]nwater aquatic life for that chemical. Where available, CCME (1999) water quali[illegible]ide[illegible]re us[illegible] Otherwise, water quality guidelines are developed in Volume 2, using [illegible]ce f[illegible]Sect[illegible]6 of this [illegible]ocument.

The protection of groundwater f[illegible]cl[illegible]ife v[illegible]ap[illegible]es only to agricultural land use (using dairy cows as receptors) and to [illegible]tura[illegible]re[illegible](g[illegible]le deer as receptors). Tolerable daily intakes of chemicals of concern, and toler[illegible]e c[illegible]ce[illegible]atio[illegible] drinking water for these receptors are developed in Volume 2.

DRAFT

4.5.2 Model Overview

The protection of groundwater model is the same as that used by CCME (2000), which, in turn is based on BCMELP (1996). The model considers four processes:

1. partitioning from soil to leachate;
2. transport of leachate from base of contamination to water table;
3. mixing of leachate and groundwater; and,
4. groundwater transport downgradient to a discharge point.

For each of these four processes, a dilution factor was calculated (DF1 through DF4, respectively). DF1 has units of (mg/kg)/(mg/L) or L/kg. The other three dilution factors are dimensionless (units of (mg/L)/(mg/L)). The overall dilution factor is used to calculate the soil concentration that is protective of a particular surface water guideline (aquatic life, livestock, or wildlife) using the following equations:

$$SQG_G = C_w DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

where:

SQG_G	=	soil quality guideline protective of groundwater for aquatic life, livestock, or wildlife watering (mg/kg);
C_w	=	water quality guideline for aquatic life, livestock, or wildlife watering (mg/L; chemical-specific parameter);
DF	=	overall dilution factor (L/kg);
DF1	=	dilution factor 1, (L/kg; calculated in following sections);
DF2	=	dilution factor 2, (dimensionless; calculated in following sections);
DF3	=	dilution factor 3, (dimensionless; calculated in following sections); and,
DF4	=	dilution factor 4, (dimensionless; calculated in following sections).

The assumptions made by the model and the equations that describe these processes are discussed in the following four sections.

DRAFT

4.5.3 Model Assumptions

Assumptions implicit in the model are the following:

- the soil is physically and chemically homogeneous;
- the moisture content is uniform throughout the unsaturated zone;
- the infiltration rate is uniform throughout the unsaturated zone;
- decay of the contaminant source is not considered (*i.e.*, infinite source mass);
- flow in the unsaturated zone is assumed to be one dimensional and downward only (vertical recharge) with dispersion, sorption-desorption, and biological degradation;
- the contaminant is not present as a free phase product;
- the maximum concentration in the leachate is equivalent to the solubility limit of the chemical in water under the defined site conditions;
- the groundwater aquifer is unconfined;
- groundwater flow is uniform and steady;
- co-solubility and oxidation/reduction effects are not considered;
- attenuation of the contaminant in the saturated zone is assumed to be one dimensional with respect to sorption-desorption, dispersion, and biological degradation;

- dispersion is assumed to occur in the longitudinal and transverse directions only and diffusion is not considered;
- mixing of the leachate with the groundwater is assumed to occur through mixing of leachate and groundwater mass fluxes; and,
- dilution of the plume by groundwater recharge down-gradient of the source is not included.

4.5.4 Dilution Factor 1

Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This "dilution factor" represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (*i.e.*, as leachate) and contaminant present as soil vapour. DF1 was calculated using the following equation:

$$DF\,1 = K_{oc} f_{oc} + \frac{(\theta_w + H'\theta_a)}{\rho_b}$$

where:

DF1	=	dilution factor 1 (L/kg);
K_{oc}	=	organic carbon partition coefficient (mL/g; chemical specific parameter);
f_{oc}	=	fraction organic carbon (g/g; see Table 2.1);
θ_w	=	moisture-filled porosity (dimensionless; see Table 2.1);
H′	=	dimensionless Henry's Law constant (chemical specific parameter);
θ_a	=	vapour-filled porosity (dimensionless; see Table 2.1); and,
ρ_b	=	dry soil bulk density (g/cm³; see Table 2.1).

DRAFT

4.5.5 Dilution Factor 2

Dilution factor 2 (DF2) is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. This dilution factor reflects a decrease in concentration as dissolved contaminant moves downwards from the base of contamination through the unsaturated zone to the water table. The decrease in concentration is due to two processes: i) dispersion in the unsaturated zone, and ii) biodegradation in the unsaturated zone. For Tier 1 calculations, the contaminant is assumed to extend to the water table, and so there is no decrease in concentration due to these processes and DF2 = 1.0. However, the equations for calculating DF2 are included here because they may be used in Tier 2 or 3 calculations.

$$DF2 = exp\left\{\frac{b}{2D_u}\left[\left(1+\frac{4D_u L_{us}}{v_u}\right)^{1/2} - 1\right]\right\}$$

$$D_u = \frac{b}{10}$$

$$L_{us} = \left(\frac{0.691}{t_{1/2us}}\right)\left(1-\frac{D_{1/2us}}{365}\right)exp(-0.07d)$$

$$v_u = \frac{IR_U}{\theta_w}$$

$$R_u = 1+\frac{\rho_b K_{oc} f_{oc}}{\theta_w}$$

where:

DF2	=	dilution factor 2 (dimensionless);
b	=	distance from base of contamination to water table (0 m; see Table 4.1);
D_u	=	dispersion in unsaturated zone (m; calcu[illegible]ove);
L_{us}	=	decay constant for chemical (ye[illegible]calcu[illegible] above);
v_u	=	mean linear leachate velo[illegible]ty (m[illegible]ar; calcu[illegible]ed above);
$t_{1/2us}$	=	chemical half life in [illegible]satu[illegible] zone (year; chemical specific parameter);
$D_{1/2us}$	=	m[illegible]um[illegible] o[illegible]ost[illegible]e[illegible]ys[illegible]ar (days; see Table 4.1);
d	=	[illegible]ti[illegible]w[illegible]ble ([illegible]a[illegible]e 4.1);
I	=	[illegible]iltra[illegible]n [illegible]e ([illegible]ve[illegible] see Table 3.2);
R_u	=	[illegible]ard[illegible]on[illegible] un[illegible]urated zone (dimensionless; calculated above);
θ_w	=	[illegible]e-filled porosity (dimensionless; see Table 2.1);
ρ_b	=	[illegible]ry bulk density (kg/L; see Table 2.1);
K_{oc}	=	organic carbon partition coefficient (mL/g; chemical specific parameter); and,
f_{oc}	=	fraction organic carbon (g/g; see Table 2.1).

DRAFT

4.5.6 Dilution Factor 3

Dilution factor 3 (DF3) is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a simple function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing

zone thickness was calculated as being due to two processes: i) mixing due to dispersion, and ii) mixing due to infiltration rate. The equations used are as follows:

$$DF3 = 1 + \frac{Z_d V}{IX}$$

$$Z_d = r + s$$

$$r = 0.01X$$

$$s = d_a \left\{ 1 - exp\left(\frac{-2.178XI}{Vd_a} \right) \right\}$$

$$V = Ki$$

where:

DF3	=	dilution factor 3 (dimensionless);
Z_d	=	average thickness of mixing zone (m; calculated above);
V	=	Darcy velocity in groundwater (m/year; calculated above);
I	=	infiltration rate (m/year; see Table 3.2);
X	=	length of contaminated soil (m; see Table
r	=	mixing depth due to dispersion (calculated above);
s	=	mixing depth due to infiltration (m; calculated above);
d_a	=	unconfined aquifer thickness (m; see Table);
K	=	aquifer hydraulic conductivity (m/year; see Table 2.1); and,
i	=	hydraulic gradient (dimensionless; see table 3.2).

DRAFT

4.5.7 Dilution Factor 4

Dilution factor 4 (DF4) accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1) downgradient of the source. The equation used to calculate this dilution factor is based on an analytical groundwater transport model (Domenico, 1987) and considers the following processes:

- advection of dissolved contaminant based on the groundwater advective flow velocity and direction;
- retardation of the advective velocity by organic matter in the aquifer;
- dispersion of the contaminant in two directions – longitudinal (*i.e.*, parallel with the groundwater flow direction, and transverse (*i.e.*, laterally in the horizontal plane); and,
- first order decay of contaminant mass (used to simulate biodegradation through the use of a contaminant half life).

Dilution factor 4 was calculated using the following equations:

$$DF4 = \frac{4}{\exp(A)\,\mathrm{erfc}(B)\,[\mathrm{erf}(C) - \mathrm{erf}(D)]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$B = \frac{x - vt\left(1 + \frac{4L_s D_x}{v}\right)^{1/2}}{2(D_x vt)^{1/2}}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.691}{t_{1/2s}} \exp(-0.07d$$

$$v = \frac{V}{\theta_t}$$

$$= \frac{\rho_s K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

DRAFT

where:

DF4	=	dilution factor 4 (dimensionless);
erf	=	the error function;
erfc	=	the complementary error function;
A	=	dimensionless group (defined above);
B	=	dimensionless group (defined above);
C	=	dimensionless group (defined above);

D	=	dimensionless group (defined above);
x	=	distance to source (m; see Table 4.1);
D_x	=	dispersivity in the direction of groundwater flow (m; calculated above);
L_s	=	decay constant ($year^{-1}$; defined above);
v	=	velocity of the contaminant (m/year; defined above);
t	=	time since contaminant release (years; see Table 4.1);
y	=	distance to receptor perpendicular to groundwater flow (m; see Table 4.1);
Y	=	source width (m; see Table 4.1);
D_y	=	dispersivity perpendicular to the direction of groundwater flow (m; calculated above);
$t_{1/2s}$	=	decay half-life of chemical in aquifer (years; chemical specific parameter);
d	=	water table depth (m; see Table 4.1);
V	=	Darcy velocity in groundwater (m/year; defined in Section 4.5.6);
θ_t	=	total soil porosity (dimensionless; see Table 2.1);
R_s	=	retardation factor in saturated zone (dimensionless; defined above);
ρ_b	=	dry soil bulk density (g/cm^3; see Table 2.1);
K_{oc}	=	organic carbon partition coefficient (mL/g; chemical specific parameter); and,
f_{oc}	=	fraction organic carbon (g/g; see Ta[illegible]).

DRAFT

5. SOIL TEXTURE AND DEPTH

5.1 General

The guidelines generated in Volume 2 include tables for Coarse and Fine surface soil and subsoil (four tables). The following sections describe how the guidelines differ between Coarse and Fine soil, and between surface soil and su[illegible]

5.2 Soil Texture

Differing guidelines for coarse and fine soils are appropriate for certain pathways. The approach used for each pathway is specified below:

5.2.1 Human Health Pathways

- Ingestion – the same guideline applies to coarse and fine soil.
- Soil Dermal Contact – the same guideline applies to coarse and fine soil.

- Indoor Vapour Inhalation – different guidelines were calculated for coarse and fine soil by substituting appropriate soil physical parameters; for details see Section 3.4.
- Protection of Potable Groundwater – different guidelines were calculated for coarse and fine soil by substituting appropriate soil physical parameters; for details see Section 3.5.

5.2.2 Ecological Health Pathways

- Plant/Invertebrate Soil Contact – Separate data were available for Coarse and Fine soil and these data were used in Volume 2 to calculate guidelines for Coarse and Fine soil for this pathway.
- Soil Ingestion – the guideline calculated for this pathway applies equally to coarse and fine soil.
- Protection of Groundwater for Freshwater Aquatic Life and Livestock/Wildlife Watering – appropriate soil parameters are used to calculate separate guidelines for coarse and fine soils; for details see Section 4.5.

5.3 Soil Depth

The approach described in the Sections 3 and 4 of this document can be used to derive guidelines that are suitably protective for surface soils. The guidelines for subsoil (defined as soil at a depth greater than 1.5 m) for certain pathways can be somewhat less stringent, based on a lower likelihood or frequency of contact. The approach to calculating subsoil guidelines [illegible] this document follows that taken in CCME (2000), and is summarized below.

DRAFT

5.3.1 Human Health Pathways

- Ingestion – not applicable [illegible] could apply to occasional exposure for construction workers, b[illegible] to h[illegible] pathway and is not calculated.
- Soil Dermal Contact [illegible] ss ground is disturbed; could apply to occasional exposure for construc[illegible] b[illegible] is not expected to be a limiting pathway and is not calculated.
- Indoor Vapour Inhalat[illegible] – different guidelines were calculated for sub soil in both the slab-on-grade and basement scenarios by changing the value of parameters Z_{crack} and/or L_T as appropriate; for details see Section 3.4.
- Protection of Potable Groundwater – the same calculation is used for surface soil and sub soil.

5.3.2 Ecological Health Pathways

- Plant/Invertebrate Soil Contact – only very deep-rooted species will be affected by contaminated subsoil, and even for those species, only a fraction of the root mass will be affected. Soil invertebrates spend the majority of their time at depths shallower than 1.5 m, and accordingly

receive only limited exposure to contaminants in subsoil. CCME (2000) generates guidelines for this pathway by multiplying corresponding surface soil guidelines by a factor between 2 and 6. In this document, subsoil guidelines for BTEX are generated by multiplying surface soil guidelines by 2, unless that would put the soil porewater concentration close to solubility for the compound. In such cases the surface soil guideline was adopted directly as the surface soil guideline.

- Soil Ingestion – does not apply as livestock and wildlife will not be directly exposed to subsoil.
- Protection of Groundwater for Freshwater Aquatic Life and Livestock/Wildlife Watering – the same calculation is used for surface soil and sub soil.

6. WATER QUALITY GUIDELINES

Two types of water quality guidelines are defined in this project.

Exposure Point water quality guidelines are applied to the water to which a receptor is actually exposed, and are used in this project as targets for calculating soil guidelines protective of various groundwater uses. Exposure Point water quality guidelines are discussed in Section 6.1 below.

Groundwater quality guidelines provide a reference value to allow a determination of the quality of groundwater, and, for some water uses, take into account the effects of certain transport processes that may occur between the point of groundwater measurement and the receptor. Groundwater quality guidelines are discussed in Section 6.2 below.

DRAFT

6.1 Exposure Point Water Quality Guidelines

The following water uses were considered:

- human drinking water;
- freshwater aquatic life;
- livestock watering; and
- wildlife watering.

Guidelines for F3, F4, and B(a)P were not required, since the low aqueous solubility and high K_{ow} of these hydrocarbons makes it unlikely that exposure to dissolved concentrations of these chemicals in water will be significant.

Where available and appropriate, CCME (1999) water quality guidelines are used. Otherwise, guidelines were calculated for this project. Example calculations are provided in Volume 2 where required.

6.2 Groundwater Quality Guidelines

Groundwater water quality guidelines were derived (Volume 2) from exposure point water quality guidelines to protect the four water uses noted above. The procedure for each water use is discussed below.

6.2.1 Human Drinking Water

The groundwater quality guidelines for human drinking water are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a drinking water well could potentially be drilled anywhere within a former upstream oil and gas facility. However, the groundwater quality guidelines for human drinking water need only be applied to aquifers defined as "Domestic Use Aquifers" by AENV (2001).

6.2.2 Livestock Watering

The groundwater quality guidelines for livestock watering are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a dugout or water well for livestock watering could potentially be installed anywhere within a former upstream oil and gas facility. The groundwater quality guideline for livestock watering need only be applied where the land use is agricultural.

DRAFT

6.2.3 Freshwater Aquatic Life and Wildlife Watering

Two cases are considered for these two water uses. Separate guidelines are derived for groundwater less than 10 m from the nearest surface water body and for groundwater more than 10 m from the nearest surface water body.

Groundwater Less Than 10 m From The Nearest Surface Water Body

For groundwater less than 10 m from the nearest surface water body ("the <10 m guidelines") the exposure point water quality guidelines are adopted directly as groundwater quality guidelines.

Groundwater More Than 10 m From The Nearest Surface Water Body

For groundwater more than 10 m from the nearest surface water body, the guidelines ("the >10 m guidelines") are less stringent than the corresponding exposure point water quality guidelines. These less stringent guidelines are based on the assumption that groundwater transport processes will result in a decrease in concentration between the point of measurement and a receptor in or drinking from a surface water body. The >10 m guidelines are calculated by dividing the corresponding exposure point water quality guideline by the dilution factor from the saturated transport part of the calculation of the

soil quality guideline for protection of ecological receptors (i.e., DF4 in Section 4.5.7). All the same parameters are used as in the calculation in Section 4.5.7, including the assumed 10 m offset.

The groundwater quality guideline for protection of freshwater aquatic life is applicable to all land uses. The groundwater quality guideline for protection of wildlife watering is only applicable to natural area land use.

DRAFT

7. REFERENCES

AECL (Atomic Energy of Canada Limited), 1990. Hydrogeology of surficial materials of permit areas D and F and the Lee River Study Area in the Whiteshell Research Area. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-498, January 1990.

AECL (Atomic Energy of Canada Limited), 1991. Hydrometeorological data for the Dead Creek Watershed, Southeastern Manitoba, 1982-1989. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-540, April 1991.

AECL (Atomic Energy of Canada Limited), 1992. Hydrogeology and hydrochemistry for the Rice Creek Watershed of the Whiteshell Research Area 1986-1990. Applied Geoscience Branch, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba. TR-570, December 1992.

AECL (Atomic Energy of Canada Limited), 1995. Hydrogeology and hydrochemistry of the Atikokan Research Area of Northwestern Ontario. Whiteshell Laboratories, Pinawa, Manitoba. TR-713, December 1992.

AENV (Alberta Environment), 2000a. A Proposed Management Framework for Reclamation and Remediation of Oil and Gas Exploration and Production Sites in Alberta. Environmental Sciences Division, Environmental Service. 4 January 2000.

AENV (Alberta Environment), 2000b. Policy for Management of Risks at Contaminated Sites in Alberta. Draft document available for comment until 1 May 20

AENV(Alberta Environment), 2001. Alberta Groundwater Q Deje ves (*in preparation*).

AEP (Alberta Environmental Protection), 1994a. berta ier I C ria for Contaminated Soil Assessment and Remediation. DRAFT. W Che Div n, Soils Protection Branch, March, 1994.

AEP (Alberta Environmental 99 . Guidelines for Petroleum Storage Tank Sites.

BCMELP (British Columbia inis ent, Lands and Parks), 1996. Overview of CSST Procedures for the D at oil Quality Matrix Standards for Contaminated Sites. BC Ministry of Environm nds and Parks.

Beyer, N., E. Connor, and S. Gerould. 1994. Estimates of soil ingestion by wildlife. *J. Wildl. Manage.*, **58**(2), 375-382.

CCME (Canadian Council of Ministers of the Environment), 1996. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. CCME-EPC-101E.

CCME (Canadian Council of Ministers of the Environment), 1997. Recommended Canadian Soil Quality Guidelines. Canadian Council of Ministers of The Environment, March, 1997.

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg.

DRAFT

CCME (Canadian Council of Ministers of the Environment), 2000. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale. Supporting Technical Document. December, 2000.

Domenico, P.A., 1987. An analytical model for multidimensional transport of a decaying contaminant species. *Journal of Hydrology*, **91**, 49-58.

Environment Canada, 2001. Canadian climate normals published on the internet at: http://www.cmc.ec.gc.ca/climate/normals/eprovndx.htm

Healy, W.B., 1968. Ingestion of soil by dairy cows. *N.Z. J. Agric. Res.*, **11**, 487-499.

Johnson, P.C. and Ettinger, R.A., 1991. Heuristic model for predicting the rate of contaminant vapors into buildings. *Environmental Science and Technology*, **25**, 1445-1452.

Keller, C.K., Van der Kamp, G., and Cherry, J.A., 1986. Fracture permeability and groundwater flow in clayey till near Saskatoon, Saskatchewan. *Canadian Geotechnical Journal*, **23**, 229-240.

NRC (National Research Council), 1996. Nutrient Requirements of Beef Cattle. National Academy Press, Washington, DC.

Smith, H.C., 1993. Alberta Mammals, An Atlas and Guide. The Provincial Museum of Alberta, Edmonton, pp. 206-207.

Suter, G.W., 1997. A Framework for Assessing Ecological Risks of Petroleum-Derived Materials in Soils. Report prepared by Oak Ridge National Laboratory (Ref: ORNL/TM-13408).

Trudell, M.R., 1994. Soil salinization associated with shallow groundwater flow systems in thin, fractured till moraine. Ph.D. thesis submitted to the [illegible] Sciences Department of the University of Waterloo, Ontario, Canada.

US EPA (United States Environmental Protection Agency), 200[illegible] IRIS online database. http://www.epa.gov/iris/

US EPA (US Environmental Protection Agency), 1993. Wildlife Exposure Factors Handbook. Volume 1 of 3. Office of Research and Development, Washington, DC. EPA/600/R-93/187a.

Wiedemeier, T.H., H.S. Rifai, C.J. Newell, and J.T. Wilson, 1999. Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface. John Wiley and Sons, New York.

Woo, M.K., and Rowsell, R.D., 1993. Hydrology of a prairie slough. *Journal of Hydrology*, **146**, 175-207.

DRAFT

Table 2.1. Generic Soil Properties

Parameter	*Symbol*	*Units*	*Coarse*	*Fine*
Definition – Median Grain Size is		µm	>75	<75
Soil Temperature [2]	T	°K	294	294
Total Soil Porosity	θ_T	*vol/vol*	0.4	0.3
Effective Soil Porosity	θ_E	*vol/vol*	0.4	0.3
Soil Water Content (=M_W/M_S)	θ_M	*mass/mass*	0.07	0.12
Moisture-Filled Porosity	θ_W	*vol/vol*	0.119	0.168
Vapour-Filled Porosity	θ_A	*vol/vol*	0.281	0.132
Soil Bulk Density (Dry Basis)	ρ_b	*g/cm³*	1.7	1.4
Soil Permeability to Vapour Flow	k_v	*cm²*	10^{-8}	10^{-9} [1]
Saturated Hydraulic Conductivity	K	*m/y*	320	0.32 [2]
Recharge Rate [3]	R	*m/y*	0.060	0.012
Fraction of Organic Carbon	f_{oc}	*mass/mass*	0.005	0.005

NOTES:

ALL PARAMETER VALUES FROM CCME (2000), EXCEPT AS NOTED;

1. ***NOT REQUIRED FOR TIER 1 CALCULATIONS;***
2. ***THIS VALUE IS REPLACED BY 32 M/Y IN THE CALCULATION OF SQG_{DW}, TO REFLECT THE MINIMUM HYDRAULIC CONDUCTIVITY OF A DOMESTIC USE AQUIFER (DUA); AND,***
3. ***CONSERVATIVE VALUES FOR ALBERTA (SEE TEXT).***

DRAFT

Table 2.2. Chemicals of Concern

Chemical of Concern	*Equivalent Carbon Number Range*	*Notes*
Benzene	na	
Toluene	na	
Ethylbenzene	na	
Xylenes	na	
Fraction F1	6-10	excluding BTEX compounds
Fraction F2	>10-16	
Fraction F3	>16-34	excluding carcinogenic PAHs [1]; not applicable to vapour or water transport pathways
Fraction F4	>34	excluding carcinogenic PAHs [1]; not applicable to vapour or water transport pathways
Carcinogenic PAHs	na	as benzo(a)pyrene equivalents

NOTES:

Hydrocarbon fractions F1 to F4 defined as per CCME (2000).

1. *Carcinogenic PAHs excluded from the definition of these fractions, however, concentrations of carcinogenic PAHs are NOT subtracted from these fractions as explained in the text.*

DRAFT

Table 2.3. Summary of Pathways

Pathway	Natural Areas	Agricultural	Residential	Commercial	Industrial
Human					
Soil Ingestion	-	✓	✓	✓	✓
Soil Dermal Contact	-	✓	✓	✓	✓
Vapour Inhalation (Indoor) [1]	-	✓	✓	✓	✓
Protection of Potable Groundwater [1]	✓	✓	✓	✓	✓
Ecological					
Soil Contact – Plants and Invertebrates	✓	✓	✓	✓	✓
Soil Ingestion – Livestock/Wildlife	✓	✓	-	-	-
Protection of Groundwater for Aquatic Life [1]	✓	✓	✓	✓	✓
Protection of Groundwater for Livestock/Wildlife Ingestion [1]	✓	✓	-	-	-

NOTES:

1. *Not calculated for CWS PHC fractions F3, F4 or B(a)P.*

DRAFT

Table 2.4. Human Receptor Parameters

Parameter	Symbol	Units	Toddler	Adult
Age Range		years	0.5-4	20+
Body Weight	BW	kg	16.5	70.7
Indoor Air Inhalation Rate	IR	m^3/d	9.3	16.2
Water Ingestion Rate	IR_W	L/d	0.6	1.5
Soil Ingestion Rate	SIR	g/d	0.08	0.02
Skin Surface Area				
Hands	SA_{HANDS}	cm^2	430	890
Other[1]	SA_{OTHER}	cm^2	2,580	2,500
Dermal Soil Loading:				
Hands	DL_{HANDS}	$mg/cm^2/event$	0.1	0.1
Other[1]	DL_{OTHER}	$mg/cm^2/event$	0.01	0.01
Dermal Exposure Frequency	EF	events/day	1	1
Exposure Term (ET) [2]	ET			
Natural Areas		(24/24)*(7/7)*(52/52)	1[4]	na
Agricultural		(24/24)*(7/7)*(52/52)	1	na
Residential		(24/24)*(7/7)*(52/52)	1	na
Commercial		(10/24)*(5/7)*(48/52)	0.27	na
Industrial		(10/24)*(5/7)*(48/52)	na	0.27
Exposure Duration (Carcinogens Only) [3]	ED	(expressed as a fraction of a full 70 year lifetime)		
Natural Areas			na	1[4]
Agricultural			na	1
Residential			na	1
Commercial			na	1
Industrial			na	1

NOTES:

All values from CCME (2000) unless otherwise specified.

na = not applicable.

1. *For adults and teens, "other" = upper and lower arms; for infants, toddlers, and children, "other" = upper and lower arms and upper and lower legs.*
2. *Exposure term is expressed as a ratio, i.e., 1.0 represents a fully exposed individual; presented only for the critical receptor in each land use.*
3. *Exposure duration shown as a ratio. As per CCME (1996), the critical receptor for carcinogen considered to be an adult who is exposed for a full 70-year life.*
4. *Protection of potable groundwater pathway only.*

DRAFT

Table 2.5. Ecological Receptor Parameters

Parameter	*Units*	*Value*	*Reference*
Dairy Cow			
Body Weight	*kg*	409	NRC (1996)
Water Ingestion Rate	*L/day*	64	NRC (1996)
Soil Ingestion Rate	*g/day*	747	Healy (1968)
Mule Deer			
Body Weight	*kg*	68	Smith (1993)
Water Ingestion Rate	*L/day*	4.4	USEPA (1993) [1]
Soil Ingestion Rate	*g/day*	44	Beyer, *et al.* (1994) [2]

NOTES:

1. ***USING ALLOMETRIC EQUATIONS FOR WATER INGESTION RATE FROM USEPA (1993).***
2. ***USING ALLOMETRIC EQUATIONS FOR FOOD INGESTION RATE FROM USEPA (1993), AND SOIL CONSUMED AS A PERCENTAGE OF FOOD INTAKE FROM BEYER ET AL. (1994).***

DRAFT

Table 3.1. Parameters for Indoor Air Inhalation Model

Parameter	*Symbol*	*Units*	*Residential*	*Residential*	*Commercial/Industrial*
Construction Type			basement	slab on grade	slab on grade
Building Length	L_B	*cm*	1,225	1,225	2,000
Building Width	W_B	*cm*	1,225	1,225	1,500
Building Height	H_B	*cm*	488	488	300
Foundation Thickness	L_{crack}	*cm*	11.25	11.25	11.25
Distance from Contamination to Slab:	L_T	*cm*			
Surface Soils			30	30	30
Subsoils			30	139	139
Area of Cracks	A_{crack}	cm^2	995	995	1,850
Length of Idealized Cylinder	X_{crack}	*cm*	4,900	4,900	7,000
Radius of Idealized Cylinder	r_{crack}	*cm*	$= A_{crack} / X_{crack}$	$= A_{crack} / X_{crack}$	$= A_{crack} / X_{crack}$
Distance Below Grade to Idealized Cylinder	Z_{crack}	*cm*	244	11.25	11.25
Air Exchanges Per Hour	ACH	*exch/hr*	1	1	2
Pressure Differential	ΔP	$g/cm\text{-}s^2$	40	40	20
Diffusivity in Cracks	D_{crack}	cm^2/sec	0.00454	0.00454	0.00454

Notes:
All values from CCME (2000).

DRAFT

Table 3.2. Parameters for Protection of Potable Groundwater Model

Parameter	*Symbol*	*Units*	*Value*
Effective Mixing Depth	B	m	2
Hydraulic Gradient	I	-	0.05
Site Length	L	m	10
Water Density	ρ_w	g/cm^3	1.0

Notes:
All values from CCME (2000).

DRAFT

Table 4.1. Parameters for Protection of Groundwater – Ecological Receptors Model

Parameter	*Symbol*	*Units*	*Value*
Contaminant Source Width	X	m	10
Contaminant Source Length	Y	m	30
Distance to Receptor (Parallel to Groundwater Flow)	x	m	10
Distance to Receptor (Perpendicular to Groundwater Flow)	y	m	0
Depth to Groundwater	d	m	3
Distance from Base of Contamination to Groundwater	b	m	0
Depth of Unconfined Aquifer	d_a	m	5
Days With Surface Temp. < 0 deg. C	$D_{1/2a}$	days	0
Time Since Contaminant Release	t	years	100

Notes:
All values from CCME (2000).

DRAFT

ALBERTA SOIL AND WATER QUALITY GUIDELINES FOR HYDROCARBONS AT UPSTREAM OIL AND GAS FACILITIES

VOLUME 2: GUIDELINE DEVELOPMENT

September 2001

DRAFT

Pub. No: T/621
ISBN: 0-7785-1896-5 Printed Edition
ISBN: 0-7785-1899-X On-line Edition
Web Site: http://www.gov.ab.ca/env/

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Land Branch
Science and Standards Division
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-5883
Fax: (780) 422-4192

or by e-mail to : Ted.Nason@gov.ab.ca

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 Guideline Overview and Document Layout 1
1.2 Sources of Chemical-Specific Information 2

2 GUIDELINE FORMAT 2
2.1 Soil Texture and Depth 2
2.2 Incorporating Canada-Wide Standard Hydrocarbon Guidelines 3
2.3 Water Quality Guidelines 3
2.4 Non Toxicity-Based Considerations 3

3 HUMAN HEALTH SOIL QUALITY GUIDELINES 4
3.1 Human Exposure Limits 5
3.2 Accounting for Background Exposure 6
3.3 Soil Ingestion 6
3.4 Soil Dermal Contact 6
3.5 Indoor Vapour Inhalation 7
3.5.1 Calculation of α for Coarse Soils 8
3.5.2 Calculation of α for Fine Soils 11
3.6 Protection of Potable Groundwater 12
3.6.1 PHC Fractions F1 and F2 12
3.6.2 BTEX Compounds 14
3.6.3 PHC Fractions F3 and F4, and B(a 14
3.6.4 Minimum Till Thickness 14
3.7 Example Calculation for Carcin ic C cals 16

4 ECOLOGICAL HEALTH GUIDEL ES 18
4.1 Plant/Invertebrat n 18
4.2 Soil Ingestion by ves k/ o 19
4.3 Protection of Gr dw r E gical Receptors 20
4.3.1 Dil n ct 21
4.3.2 Dil actor 2 22
4.3.3 Dilution Factor 3 22
4.3.4 Dilution Factor 4 23

5 WATER QUALITY GUIDELINES 24
5.1 Exposure Point Water Quality Guidelines 25
5.1.1 Human Drinking Water 25
5.1.2 Freshwater Aquatic Life 26
5.1.3 Livestock and Wildlife Watering 27
5.2 Groundwater Quality Guidelines 27
5.2.1 Human Drinking Water 27

DRAFT

5.2.2 Livestock Watering 28
5.2.3 Freshwater Aquatic Life and Wildlife Watering 28

6 REFERENCES 29

APPENDIX A

A1. INTRODUCTION 32

A2. PLANTS, SOIL INVERTEBRATES AND MICRO-ORGANISMS 32
A2.1 Review of Existing Data 32
A2.1.1 Benzene 32
A2.1.2 Toluene 33
A2.1.3 Ethylbenzene 35
A2.1.4 Xylenes 36
A2.2 New Data 37

A3. LIVESTOCK/WILDLIFE 39
A3.1 Benzene 39
A3.2 Toluene 39
A3.3 Ethylbenzene 40
A3.4 Xylenes 40

A4. FRESHWATER AQUATIC LIFE 40

A5. REFERENCES 42

DRAFT

LIST OF TABLES

Table 1.1 Chemical-Specific Data
Table 1.2 Chemical-Specific Data F1 and F2 Subfractions
Table 1.3 Chemical-Specific Data F3 and F4
Table 2.1 Alberta Tier 1 Hydrocarbon Guidelines for Fine Surface Soil
Table 2.2 Alberta Tier 1 Hydrocarbon Guidelines for Coarse Surface Soil
Table 2.3 Alberta Hydrocarbon Guidelines for Fine Subsoil
Table 2.4 Alberta Hydrocarbon Guidelines for Coarse Subsoil
Table 5.1 Exposure Point Water Quality Guidelines
Table 5.2 Groundwater Quality Guidelines

Table A1 Combined IC50/LC50 Data – Alberta Till (Fine)
Table A2 Combined IC50/LC50 Data - Artificial Soil (Coarse)
Table A3 Freshwater Aquatic Toxicity Data For Xylenes
Table A4 Reduced Freshwater Aquatic Toxicity Dataset For Xylenes

1 INTRODUCTION

The operation of upstream oil and gas facilities can result in the release of hydrocarbon compounds to the environment. This can be a concern either during the operation of the facility, or after decommissioning when land is returned to its former use. Site closure is a term often used to describe regulatory acceptance that decommissioning is complete, and the land is ready to revert to its former or a new use. The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* were developed to assist in environmental management and site closure of upstream oil and gas facilities in Alberta.

The upstream sector of the oil and gas industry includes activities associated with the extraction of oil and gas from the subsurface up to the point it reaches the refinery. Examples of upstream oil and gas facilities include well sites and gas plants. Refineries and facilities for the distribution and sale of refined products are not part of the upstream sector. These guidelines specifically address releases of hydrocarbon mixtures from the upstream sector.

1.1 Guideline Overview and Document Layout

The *Alberta Soil and Water Quality Guidelines for Upstream Oil and Gas Sites* are presented in three volumes:

Volume 1	Protocol;
Volume 2	Guideline Development; and,
Volume 3	User Guidance,

Volume 1 includes an overview of the project, provides [illegible]kgr[illegible]nd r[illegible]nale for the approach used, and develops the technical protocol t[illegible]ed [illegible]ide[illegible] develo[illegible]ent. Volume 2 (this document) provides all chemical-sp[illegible] inf[illegible]n, a[illegible]str[illegible]s how the protocol developed in Volume 1 was used to develop gu[illegible] V[illegible]3 s[illegible]e guideline values, and provides user guidance. Volume 3 provides all th[illegible]nfo[illegible]at[illegible]r[illegible]ire[illegible]y users of generic guidelines. Users wishing to develop modified generic guideli[illegible]s or [illegible]te-[illegible]ecif[illegible]remediation objectives will find useful information in all 3 volumes.

DRAFT

The remainder of the current document (Volume 2) is organized as follows. Section 1.2 summarizes all of the chemical-specific data used in the guideline development process. Section 2 discusses the guideline format. Section 3 provides example calculations for the human health exposure pathways. Section 4 provides example calculations for the ecological health exposure pathways. Section 5 provides examples of the derivation of water quality guidelines. References are included in Section 6.

Volume 3 is the critical document for the application of these guidelines. Certain procedures and conditions described below have limited application as described in Volume 3.

1.2 Sources of Chemical-Specific Information

The protocol document (Volume 1) included values for all non-chemical-specific parameters that are required for guideline development. Chemical-specific parameters for BTEX and B(a)P (benzo(a)pyrene) are summarized in Table 1.1. Chemical-specific parameters for PHC sub-fractions and fractions are summarized in Tables 1.2 and 1.3, respectively. The source of each parameter is indicated in each Table.

2 GUIDELINE FORMAT

The guidelines for BTEX and B(a)P generated in this report, together with the guidelines for the 4 PHC fractions adopted or adapted from CCME (2000), are provided in Tables 2.1 to 2.4 as follows:

- Table 2.1: Alberta Tier 1 Guidelines for Fine Surface Soil;
- Table 2.2: Alberta Tier 1 Guidelines for Coarse Surface Soil;
- Table 2.3: Alberta Guidelines for Fine Subsoil; and,
- Table 2.4: Alberta Guidelines for Coarse Subsoil.

The following points should be noted in conjunction with these tables:

- the lowest value for each chemical and land use in each Table is bold;
- PHC guidelines that have been adopted without change from CCME (2000) are underlined;
- the guidelines calculated for the protection of groundwater aquatic life, and wildlife watering pathways may not apply at a given site where groundwater contains
- values exceeding 30,000 mg/kg (the solubility limit used by CCME, 2000) for formation of residual hydrocarbon) are recorded as "NES" (no
- all guideline values are rounded to 2 significant figures.

DRAFT

Example calculations are provided in this volume to illustrate the guideline derivation process. Note that the equations in this document follow standard mathematical convention in that multiplication is indicated by two parameters being adjacent with no operator symbol between them. Where this convention might be ambiguous, the multiplication operator (×) is used explicitly.

2.1 Soil Texture and Depth

The protocols described in Volume 1 were used to generate four tables of soil guidelines (Tables 2.1 to 2.4). Each table presents the soil quality guidelines for a group of chemicals of concern for all pathways and all land uses for one soil texture and depth. Four tables are required to allow for the inclusion of two soil textures (Coarse and Fine) and two soil depths (surface and subsoil).

The guidelines for some pathways apply equally to different soil textures or soil depths. Other guidelines are calculated differently for differing soil textures and/or depths. Further discussion of how guidelines for different soil textures or depths were calculated was included in Volume 1. Some of the calculations used to calculate guidelines for differing soil textures or depths are based on risk management decisions made in CCME (2000) and are discussed in Volume 1.

2.2 Incorporating Canada-Wide Standard Hydrocarbon Guidelines

The Canada-Wide Standard for Petroleum Hydrocarbons (CCME, 2000) developed generic levels for four hydrocarbon fractions, F1 to F4, and four land uses. Where appropriate, these generic levels are used without modification as guidelines in the current work. However, for groundwater pathways (protection of human, livestock, and wildlife drinking water and freshwater aquatic life) the guidelines are recalculated to reflect the Alberta-specific recharge values of 0.060 m/year and 0.012 m/year for Coarse and Fine soils, respectively. In addition, guidelines are calculated for natural area land use, which is within the scope of the current work, but outside the scope of the PHC Canada-Wide Standard. Based on the scenario described in Volume 1, guidelines for natural areas are calculated using the same equations as for agricultural land use with two changes: i) the human soil ingestion, soil dermal contact, and indoor vapour inhalation pathways are excluded; and, ii) [illegible] is substituted for a dairy cow as the livestock/wildlife receptor for the soil ingestion [illegible]n of groundwater for livestock/wildlife watering pathways.

DRAFT

2.3 Water Quality Guidelines

Two types of water quality guide[illegible] u[illegible] the[illegible]k. Exposure point water quality guidelines are the limiting concen[illegible]tio[illegible]in[illegible]at[illegible]o[illegible]hich a receptor is actually exposed. These guidelines are used as water qualit[illegible]arg[illegible] f[illegible]he [illegible]otection of groundwater pathways. Groundwater guidelines are used to assess wh[illegible]e[illegible]ent[illegible]ions of contaminants are acceptable in groundwater. Water quality guidelines are comp[illegible]or calculated in Section 5 for BTEX, F1, and F2 for human drinking water, protection of freshwater aquatic life, and livestock and wildlife watering.

2.4 Non Toxicity-Based Considerations

In addition to the toxic risks addressed by receptor/pathway analyses, certain other management considerations apply. Chief among these are:

- ignition hazard;
- odour and appearance; and,
- formation of non-aqueous phase liquids (NAPL).

Whereas the primary focus in this project is prevention of toxic effects to human and ecological receptors, in certain situations these pathways may be of little immediate concern and contaminant management is driven by consideration of policy factors (CCME, 2000). Aesthetics and avoidance of free product considerations were incorporated as policy factors in the development of the PHC Canada-Wide Standard (CCME, 2000). Many of the same policy decisions are adopted in this document. In particular, removal of free product will normally be a requirement of any remedial action plan.

One issue that required further discussion is ignition hazard. The lower explosive limits (LELs) is a measure of the minimum concentration of a compound in air that will burn in air when a source of ignition is present. Hydrocarbon LEL values are well documented, and, for most compounds, are close to 10,000 parts per million by volume (ppmv). It is more difficult to determine what hydrocarbon soil concentration presents a risk of fire or explosion. The worst possible case would be a closed volume of air in equilibrium with hydrocarbon contaminated soil. However, in reality, it is likely that air movement and volatilization kinetics will always ensure that actual concentrations in air are well below the worst case scenario.

Initial calculations show that BTEX concentrations at or below the soil quality guidelines calculated in this document would not result in vapour concentrations above 20% of L[illegible]n in the worst case scenario. It is unlikely, therefore, that ignition hazard will be a signifi[illegible]ration in setting BTEX soil quality guidelines.

It is not so clear whether ignition hazard should [illegible]side[illegible]her[illegible]ing soil[illegible]ality guidelines for the volatile PHC fractions. However, this issue[illegible]as[illegible]t a[illegible]re[illegible]d [illegible]the PHC Canada-Wide Standard (CCME, 2000), and so, for co[illegible], [illegible]emp[illegible]e[illegible]ade to address it here. It is recommended, however, that this is[illegible]e b[illegible]iv[illegible]ul [illegible]isid[illegible]ation when the time comes for a review of the PHC Canada-Wide Standar[illegible]

Based on the above discussion, no [illegible]ctions were made to the guidelines calculated in this project to account for ignition hazard.

DRAFT

3 HUMAN HEALTH SOIL QUALITY GUIDELINES

This section discusses the human health toxicological exposure limits for the chemicals of concern and describes the development of guidelines for the human health pathways for BTEX, B(a)P, and PHC fractions F1 to F4. The human health guidelines were developed based on exposure to an adult

receptor for the carcinogenic chemicals (*i.e.*, benzene and B(a)P). For the non-carcinogenic chemicals (*i.e.*, toluene, ethylbenzene and xylenes and PHC fractions F1 to F4), exposure to an adult receptor was considered in the industrial scenario, and exposure to a child receptor (aged 7 months to 4 years) in the agricultural, residential, and commercial scenarios.

Example calculations are provided, using toluene as the chemical of concern, and a residential scenario for each of the human health pathways examined (*i.e.*, soil ingestion, soil dermal contact, indoor vapour inhalation, and ingestion of contaminated groundwater). Where applicable, separate calculations are provided for Coarse and Fine soils. In addition, the soil ingestion guideline is calculated for benzene to provide an example of a guideline calculation for a carcinogenic compound.

3.1 Human Exposure Limits

The human health soil quality guidelines developed in the following sections are based on a human health exposure limit, which reflects the dose or concentration of the chemical of concern that is considered unlikely to cause adverse health effects in sensitive humans. The exposure limits for BTEX and B(a)P are included in Table 1.1. The exposure limits for the PHC sub-fractions are included in Table 1.2. The source of each exposure limit is included as a footnote with the applicable table. The approach taken to develop the exposure limits for the chemicals of concern was to use regulatory-approved limits, where available, in the following order of preference:

- Health Canada (Health Canada, 1996a);
- United States Environmental Protection Agency IRIS database (US EP[illegible]; and,
- Canada-Wide Standards for PHC in Soil (CCME, 2000).

Benzene and B(a)P are classified as carcinogens by Hea[illegible]ana[illegible]96a). Toluene, ethylbenzene, xylenes and all four PHC fractions are classifi[illegible]n-c[illegible]ger[illegible] For the [illegible]cinogens, risk-specific doses (RsD) or risk-specific concentrati[illegible]s ([illegible]) [illegible]re d[illegible]ve[illegible]ed[illegible]ch that exposure to the chemicals of concern would not result in an [illegible]nt[illegible]er r[illegible]o[illegible] than 1 in 100,000 (*i.e.*, 1×10^{-5}) above background incidence.

For the non-carcinogens, regulato[illegible]li[illegible]s f[illegible]oral or inhalation exposure were used directly as the tolerable daily intake (TDI) or refe[illegible] concentration (RC).

DRAFT

3.2 Accounting for Background Exposure

Background exposure was addressed in two ways. Firstly, the possibility of receptors being exposed to levels of hydrocarbon contamination in background soils was considered, and included in the equations provided in Volume 1 to calculate human pathways. However, the background level of all the chemicals of concern considered in this project is assumed to be 0.

Secondly, it is recognized (CCME, 1996) that exposure to the chemicals of concern can occur via other media than soil (*e.g.*, water, air, food, and consumer products). Accordingly, the soil quality guidelines incorporated a soil allocation factor (SAF), that was used to determine what fraction of the total acceptable exposure was allocated to exposure via contaminated soil. SAF values for BTEX were taken from the SAF for hydrocarbon fraction F1 (CCME, 2000). The value for BaP was taken from the SAF for hydrocarbon fraction F3 (CCME, 2000). SAF values are summarized in Tables 1.1 and 1.3.

3.3 Soil Ingestion

The soil quality guidelines calculated for the soil ingestion pathway (SQG_{SI}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. The following equation was used to calculate the SQG_{SI}. Data for toluene in a residential land use scenario are provided as an example:

$$SQG_{SI} = \frac{(TDI - EDI) \times SAF \times BW \times 10^3}{SIR \times AF_G \times ET} + [$$

DRAFT

Where:

SQG_{SI}	=	human health soil quality g[illegible] ingest[illegible]n (mg/kg);
TDI	=	tolerable daily [illegible]0.2[illegible]kg-[illegible]/day; see [illegible]able 1.1);
EDI	=	estima[illegible] dail[illegible]nta[illegible] (0.[illegible]2[illegible]g/[illegible]-bw/day; see Table 1.1);
SAF	=	soi[illegible] [illegible]on[illegible] (0.5[illegible]ol[illegible].1);
BW	=	tod[illegible]r b[illegible]y [illegible]g[illegible]16[illegible]kg; see Volume 1 Table 2.4);
10^3	=	con[illegible]rsio[illegible]fac[illegible]r fr[illegible]kg to g;
SIR	=	soi[illegible]g[illegible]on [illegible]e for the toddler (0.08 g/day; see Volume 1 Table 2.4);
AF_G	=	abs[illegible]on factor for gut (1; see Table 1.1);
ET	=	exposure term for residential use (1; see Volume 1 Table 2.4); and,
BSC	=	background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 22,000 mg/kg, which is the guideline for incidental human soil ingestion for toluene in a residential setting (SQG_{SI}) (Tables 2.1 and 2.2).

3.4 Soil Dermal Contact

The soil quality guidelines calculated for the soil dermal contact pathway (SQG_{DC}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. The following equation was used to calculate the SQG_{DC}. Data for toluene in a residential land use scenario are provided as an example:

$$SQG_{DC} = \frac{(TDI - EDI) \times SAF \times BW \times 10^6}{AF_D \times \{(SA_{HANDS} \times DL_{HANDS}) + (SA_{OTHER} \times DL_{OTHER})\} \times EF \times ET} + [BSC]$$

Where:

- SQG_{DC} = human health soil quality guideline for soil dermal contact (mg/kg);
- TDI = tolerable daily intake (0.22 mg/kg-bw/day; see Table 1.1);
- EDI = estimated daily intake (0.0028 mg/kg-bw/day; see Table 1.1);
- SAF = soil allocation factor (0.5; see Table 1.1);
- BW = toddler body weight (16.5 kg; see Volume 1 Table 2.4);
- 10^6 = conversion factor from kg to mg;
- AF_D = absorption factor for soil dermal contact (0.12; see Table 1.1);
- SA_{hands} = toddler hand surface area (430 cm^2; see Volume 1 Table 2.4);
- DL_{hands} = dermal soil loading for a toddler's hands (0.1 mg/cm^2-event; see Volume 1 Table 2.4);
- SA_{other} = surface area for other exposed skin (2,580 cm^2; see Volume 1 Table 2.4);
- DL_{other} = dermal soil loading for other exposed skin (0.01 mg/cm^2-event; see Volume 1 Table 2.4);
- EF = exposure frequency (1 event/day; see Volu[illegible]ble 2.4)
- ET = exposure term for residential use (1[illegible]1 Table 2.4); and,
- BSC = background soil concentrati[illegible](0 m[illegible]kg; see T[illegible]e 1.1).

Substituting these values in the above equati[illegible]our[illegible]o 2 [illegible]gnificant[illegible]gures yields a value of 220,000 mg/kg. This value is gre[illegible]an[illegible]e [illegible]um[illegible]er [illegible]nit of 30,000 mg/kg for residual hydrocarbon formation, and so the[illegible]e [illegible]man[illegible]m contact for toluene in Coarse soil (SQG_{SI}) is reported in Table 2.2 as [illegible]ES[illegible]

DRAFT

3.5 Indoor Vapour Inhalati[illegible]

The soil quality guidelines calculated for the indoor vapour inhalation pathway (SQG_{II}) are presented in Tables 2.1 to 2.4. The guidelines for PHC fractions F1 to F4 were adopted from the generic levels in CCME (2000) without change. An SQG_{ii} was not calculated for B(a)P because B(a)P is not volatile, and thus would not have an appreciable indoor air concentration. The following equation was used to calculate the SQG_{II}. Data for toluene in the residential land use scenario for both Coarse and Fine surface soil in a house with a basement, are provided as examples:

$$SQG_{II} = \frac{(RfC - C_a) \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times SAF \times DF_I \times 10^3}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:

SQG_{II}	=	soil quality guideline for indoor infiltration (mg/kg);
RfC	=	reference concentration (3.8 mg/m^3; see Table 1.1);
C_a	=	background indoor air concentration (0.005 mg/m^3; see Table 1.1);
θ_w	=	moisture-filled porosity (0.119 (Coarse soil) or 0.168 (Fine-texture soil); see Volume 1 Table 2.1);
K_{oc}	=	organic carbon partition coefficient (234 mL/g; see Table 1.1);
f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1);
ρ_b	=	dry soil bulk density (1.7 g/cm^3 (Coarse soil) or 1.4 g/cm^3 (Fine soil); see Volume 1 Table 2.1);
H'	=	dimensionless Henry's Law Constant (0.274; see Table 1.1);
θ_a	=	vapour-filled porosity (0.281 (Coarse soil) or 0.132 (Fine soil); see Volume 1 Table 2.1);
SAF	=	soil allocation factor (0.5; see Table 1.1);
DF_I	=	dilution factor from soil gas to indoor air (22,500 (Coarse soil) or 509,000 (Fine soil); see derivation below);
10^3	=	conversion factor from kg to g;
ET	=	exposure term for residential (1; see Volume 1 Table 2.4);
10^6	=	conversion factor from m^3 to cm^3; and,
BSC	=	background soil concentration (0 mg/kg; see Table 1.1).

Substituting these values in the above equations and rounding to [illegible] significant figures yields values of 4,600 mg/kg (Fine soil) and 200 mg/kg (Coarse soil) which [illegible] the guidelines [illegible] human indoor vapour inhalation of toluene in a residential scenario in a building [illegible] basement (SQG$_{II}$) (Tables 2.1 and 2.2, respectively).

DRAFT

The dilution factor (DF_I) was calculated as follows:

$$DF_I = \frac{1}{\alpha}$$

Where:

DF_I	=	dilution factor from soil gas concentration to indoor air concentration (unitless); and,
α	=	attenuation coefficient (unitless; see derivation below).

3.5.1 Calculation of α for Coarse Soils

The attenuation coefficient for Coarse soils was calculated using the following equation:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right)}{\left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right) + 1}$$

Where:
- α = attenuation coefficient (unitless);
- D_T^{eff} = effective porous media diffusion coefficient (0.00790 cm^2/s; see derivation below);
- A_B = building area (2,700,000 cm^2; see derivation below);
- Q_B = building ventilation rate (203,000 cm^3/s; see derivation below);
- L_T = distance from contaminant source to foundation (30 cm; see Volume 1 Table 3.1); and,
- Q_{soil} = volumetric flow rate of soil gas into the building (9.14 cm^3/s; see derivation below).

Substituting these values in the above equations yields a value for α of 4.44×10^{-5}, corresponding to a dilution factor of 22,500.

Calculation of D_T^{eff}:

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2}\right)$$

Where:
- D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentration for the distance between the source and foundation (cm^2/s);
- D_a = diffusion coefficient in air (0.08 cm^2/s; see Table 1.1);
- θ_a = soil vapour-filled porosity (0.281; see Volume 1 Table 2.1); and,
- θ_t = soil total porosity (0.4; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for D_T^{eff} of 0.00790 cm^2/s.

Calculation of A_B:

A_B is the entire below ground surface area of the building, *i.e.,* the footprint area plus the area of walls below ground, and is calculated as follows:

$$A_B = (L_B W_B) + 2Z_{crack}(L_B + W_B)$$

DRAFT

Where: A_B = below ground building area (cm^2);
L_B = building length (1,225 cm; see Volume 1 Table 3.1);
W_B = building width (1,225 cm; see Volume 1 Table 3.1); and,
Z_{crack} = distance below ground to idealized cylinder (*i.e.*, basement depth below ground; 244 cm; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for A_B of 2,700,000 cm^2.

Calculation of Q_B:

$$Q_B = \frac{L_B W_B H_B ACH}{3{,}600}$$

Where: Q_B = building ventilation rate (cm^3/s);
L_B = building length (1,225 cm; see Volume 1 Table 3.1);
W_B = building width (1,225 cm; see Volume 1 Table 3.1);
H_B = building height, including basement (488 cm; see Volume 1 Table 3.1);
ACH = air exchanges per hour (1 h^{-1}; see Volume 1 Table 3.1); and,
3,600 = conversion factor from hours to seconds.

Substituting these values in the above equations yields a value for Q_B of 203,000 cm^2.

Calculation of Q_{soil}:

$$Q_{soil} = \frac{2\pi\Delta P k_v X_{crack}}{\mu \ln\left[\frac{2Z_{crack}}{r_{crack}}\right]}$$

DRAFT

Where Q_{soil} = volumetric flow of soil gas into the building (cm^3/s);
ΔP = pressure differential (0 $g/cm \cdot s^2$; see Volume 1 Table 3.1);
k_v = soil intrinsic permeability to vapour flow (1.0 x 10^{-8} cm^2; see Volume 1 Table 3.1);
X_{crack} = length of idealized cylinder (4,900 cm; see Volume 1 Table 3.1);
μ = vapour viscosity (0.000173 g/cm·s; see Volume 1 Table 3.1);
Z_{crack} = distance below grade to idealized cylinder (244 cm; see Volume 1 Table 3.1); and,
r_{crack} = radius of idealized cylinder (0.203 cm; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for Q_{soil} of 9.14 cm^3/s.

3.5.2 Calculation of α for Fine Soils

The attenuation coefficient for Fine soils was calculated using the following equation:

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right)}{1 + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B L_{crack}}{D_{crack} A_{crack} L_T}\right)}$$

Where:
- α = attenuation coefficient (unitless);
- D_T^{eff} = effective porous media diffusion coefficient (0.00113 cm^2/s; see derivation below);
- A_B = building area (2,700,000 cm^2; see derivation above for Coarse soil);
- Q_B = building ventilation rate (203,000 cm^3/s; see derivation above for Coarse soil);
- L_T = distance from contaminant source to foundation (30 cm; see Volume 1 Table 3.1);
- L_{crack} = thickness of the foundation (11.25 cm; see Volume 1 Table 3.1);
- D_{crack} = effective vapour-pressure diffusion coefficient through the crack (0.00454 cm^2/s; see Volume 1 Table 3.1); and,
- A_{crack} = area of cracks through which contaminant vapours enter building (995 cm^2; see Volume 1 Table 3.1).

Substituting these values in the above equations yields a value for α of 1.97×10^{-6}, corresponding to a dilution factor of 509,000.

DRAFT

Calculation of D_T^{eff}:

$$D_T^{eff} = D_a \left(\frac{\theta_a^3}{\theta_t^2}\right)$$

Where:
- D_T^{eff} = overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm^2/s);
- D_a = diffusion coefficient in air (0.087 cm^2/s; see Table 1.1);
- θ_a = soil vapour filled porosity (0.132; see Volume 1 Table 2.1); and,
- θ_t = soil total porosity (0.3; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for D_T^{eff} of 0.00113 cm^2/s.

3.6 Protection of Potable Groundwater

The soil quality guidelines calculated for the protection of potable groundwater pathway (SQG_{GW}) are presented in Tables 2.1 to 2.4.

3.6.1 PHC Fractions F1 and F2

The SQG_{GW} for PHC fractions F1 and F2 are recalculated from the Canada-Wide Standard values by substituting the Alberta-specific recharge value (0.060 m/year and 0.012 m/year for Coarse and Fine soils, respectively) in the Canada-Wide Standard algorithm.

Calculation of Guideline for Sub-Fraction

Data for the aromatic $C_{>8}$-C_{10} sub-fraction of fraction F1 in the residential land use scenario for Coarse soil is provided below as an example:

$$SQG_{GWi} = \frac{(TDI - EDI) \times (K_d + (\theta_m / \rho_w)) \times BW \times DF_W}{IR_W} + BSC$$

Where:

SQG_{GWi}= soil quality guideline for protection of potable groundwater for sub-fraction "i" (in this case "i" is the aromatic $C_{>8}$-C_{10} sub-fraction; mg/kg);

TDI = tolerable daily intake for aromatic $C_{>8}$-C_{10} sub-fraction (0.04 mg/kg-bw/day; see Table 1.2);

EDI = estimated daily intake aromatic $C_{>8}$-C_{10} sub-fraction (0.00938 mg/kg-bw/day; see Table 1.2);

K_d = distribution coefficient (7 mL/g; (1,580 mL/g) x f_{oc} (0.005); see Table and Volume 1 Table 3.1);

θ_m = ratio of mass of water in mass of soil (0.07 g/g; see Volume 1 Table 2.1);

ρ_w = density of water (1.0 g/cm^3; see Volume 1 Table 3.2);

BW = toddler body weight (16.5 kg; see Volume 1 Table 2.4);

DF_W = groundwater/pore water dilution factor (54.3 for Coarse soils; see derivation below);

IR_W = ingestion rate of water for toddler (0.6 L/day; see Volume 1 Table 2.4); and,

BSC = background soil concentration (0 mg/kg; see Table 1.1).

DRAFT

Substituting these values in the above equations and rounding to 3 significant figures yields a value of 366 mg/kg which is the guideline for protection of potable groundwater in Coarse soil for the aromatic $C_{>8}$-C_{10} sub-fraction (SQG_{GW}).

The above calculation for the aromatic $C_{>8}$-C_{10} sub-fraction, and similar calculations for the other F1 sub-fractions yield values (SQG_{Gwi}) that are tabulated below, together with the assumed proportion of each fraction (F_i):

Sub-Fraction	***SQG_{GWi} (mg/kg)***	***F_i***
aliphatic $C_{>6}$-C_8	149,000	0.55
aliphatic $C_{>8}$-C_{10}	21,200	0.36
aromatic $C_{>8}$-C_{10}	366	0.09

The overall SQG_{GW} for F1 is then calculated by using the following formula:

$$SQG_{GW}(mg/kg-bw/day) = \frac{1}{\sum_i \frac{F_i}{SQG_{GWi}}}$$

where:

SQG_{GW} = soil quality guideline for protection of potable groundwater (mg/kg);

F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,

SQG_{GWi} = soil quality guideline for protection of potable groundwater for sub-fraction "i" (mg/kg).

Substituting the above values in this equation and rounding to significant figures yields a value of 3,700 mg/kg which is the guideline for protection of potable groundwater in Coarse soil for PHC fraction F1 (SQG_{GW}), Table 2.2.

DRAFT

Calculation of Dilution Factor

The dilution factor was calculated as follows:

$$DF_w = \frac{BKi}{IL} + 1$$

Where:

DF_W = groundwater/pore water dilution factor (unitless);

B = effective mixing depth in aquifer (2 m; see Volume 1 Table 3.2);

K = saturated hydraulic conductivity of aquifer (320 m/y (Coarse soil) or 32 m/y (Fine soil); see Volume 1 Table 2.1);

i = hydraulic gradient (0.05 ; see Volume 1 Table 3.2);

I	=	infiltration (recharge) rate (0.060 m/y for Coarse soil or 0.012 m/y for Fine soil; see Volume 1 Table 2.1); and,
L	=	site length (10 m; see Volume 1 Table 3.2).

Substituting these values in the above equations yields values for the dilution factor of 54.3 (Coarse soil) and 27.7 (Fine soil).

3.6.2 BTEX Compounds

The SQG_{GW} for the BTEX compounds are calculated using the same formula as for F1 and F2, adapted to use the Canadian Drinking Water Quality Guidelines (Health Canada, 1996b) as the toxicological basis, rather than the TDI. Data for toluene in the residential land use scenario for Coarse soil are provided below as an example:

$$SQG_{GW} = C_{DW}(K_d + (\theta_m / \rho_w))DF_w + BSC$$

Where: SQG_{GW}	=	soil quality guideline for protection of potable groundwater (mg/kg);
C_{DW}	=	drinking water quality guideline (0.024 mg/L; Table 5.1);
K_d	=	chemical-specific distribution coefficient (1.17 mL/g; K_{oc} (234 mL/g) x f_{oc} (0.005); see Table 1.1 and Volume 1 Table 2.1);
θ_m	=	ratio of mass of water in soil/dry mass of soil (0.07 g/g; see Volume 1 Table 2.1);
ρ_w	=	density of water (1.0 g/cm^3; see Volume 1 [illegible]);
DF_w	=	groundwater/pore water dilution fa[illegible]; derivation in Section 3.6.2 above);
BSC	=	background soil concentra[illegible] (0 m[illegible] see T[illegible]e 1.1).

Substituting these values in the above [illegible]atic[illegible] an[illegible]rou[illegible]n[illegible] 2 [illegible]gnificant figures yields a value of 0.86 mg/kg which is the guideli[illegible]or [illegible]te[illegible]f p[illegible]o[illegible]dwater in Coarse soil for toluene (SQG_{GW}).

DRAFT

3.6.3 PHC Fractions F3 and F[illegible]d B(a)P

No guidelines for these groups or compounds are calculated for these pathways based on their extremely limited aqueous solubility and subsurface mobility.

3.6.4 Minimum Till Thickness

At some sites, a sufficient thickness of till may be present between contaminated soil and an underlying domestic use aquifer (DUA), such that contaminant concentrations in the DUA are not expected to

exceed respective drinking water quality guidelines. In such cases, the guideline for the protection of groundwater for drinking water pathway need not be applied. Based on a screening level calculation, the minimum thickness of saturated Fine material, with a measured bulk hydraulic conductivity of 10^{-7} m/s or less ($K<10^{-7}$ m/s), required to exclude this pathway is 5 m. The calculations below explain how this thickness was determined.

The calculation was based on the following assumptions:

- it was assumed as a worst case that hydrocarbon compounds were each present in pore water at the contaminant source at their respective solubilities;
- dissolved hydrocarbon components are assumed to travel downwards through till underlying the contaminant source;
- hydrocarbon concentrations are assumed to decrease due to biodegradation at the rates used in the ecological groundwater model (Section 4.3); and,
- upon reaching the DUA, it is assumed that there is dilution due to mixing as calculated in Section 3.6.1 above.

The above assumptions were used to calculate the minimum thickness of till (L_{min}) required to ensure that concentrations of each of the hydrocarbon chemicals of concern do not exceed drinking water guidelines in the DUA using the following equation. The calculation for benzene (the most mobile of the hydrocarbon compounds) is provided as an example:

$$L_{min} = \frac{Log(S/DWQG \times DF)}{Log(2)} \times \frac{Kit_{1/2}}{R\theta}$$

DRAFT

Where:

L_{min}	=	minimum till thickness as d[illegible]d a[illegible]
Log	=	logarithm ope[illegible]se [illegible]
S	=	solubili[illegible]f c[illegible]po[illegible]d ([illegible]80[illegible]g/[illegible]or benzene; Table 1.1);
DWQG	=	dri[illegible]ate[illegible]ity [illegible]r component (0.005 mg/L for ben[illegible]ne; [illegible]b[illegible].
DF	=	dilu[illegible]n f[illegible]or p[illegible]water/aquifer mixing, Fine soil (27.7; calculated in S[illegible]ti[illegible]3.6[illegible] above);
K	=	sat[illegible] vertical hydraulic conductivity in till (3.15 m/year, based on an assumed hydraulic conductivity of 10^{-7} m/s);
i	=	vertical hydraulic gradient in saturated till (0.1; assumed reasonable worst case);
$t_{1/2}$	=	half life of compound (1 year for benzene, Table 1.1);
R_s	=	retardation factor in saturated zone (2.89; calculated below); and,
θ_t	=	total porosity for Fine soil (0.3; see Volume 1, Table 2.1).

Substituting these values for benzene in the above equation, and rounding to the nearest meter, yields a value for the minimum till thickness of 5 m, using benzene as an example. Performing this calculation for other hydrocarbon compounds shows that benzene is the limiting compound, and accordingly 5 m is adopted as the minimum thickness of Fine material ($K<10^{-7}$ m/s) required to exclude the protection of groundwater for drinking water pathway.

It should be noted that this calculation contains many conservative assumptions. In particular the requirement is that the measured bulk hydraulic conductivity of the material is less than 10^{-7} m/s. Commonly-used methods of measuring bulk hydraulic conductivity in the field (*e.g.*, rising head test) measure *horizontal* hydraulic conductivity. The above calculations are based on *vertical* hydraulic conductivity. Vertical hydraulic conductivities are often assumed to be an order of magnitude lower than horizontal values in sedimentary materials such as till, and so significant conservatism is introduced into this screening level calculation.

Retardation Factor

The retardation factor is calculated using the following equation:

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

where:

R_s	=	retardation factor in saturated zone;
ρ_b	=	dry soil bulk density (Fine soil: 1.4 g/cm^3; s[illegible]e 1 Table 2.1);
K_{oc}	=	organic carbon partition coefficient ([illegible] ee Table 1.1);
f_{oc}	=	fraction organic carbon (0.00[illegible] g/g; [illegible] Volum[illegible] Table 2.1); and,
θ_t	=	total soil porosity (Fine soi[illegible]30; s[illegible]ume[illegible]able 2.1).

Substituting these values in the above [illegible]atio[illegible] yi[illegible]s a [illegible]alu[illegible]or[illegible] retardation factor for benzene in Fine soil of 2.89.

DRAFT

3.7 Example Calculation fo[illegible]Ca[illegible]n[illegible]enic Chemicals

Guidelines for carcinogenic chemi[illegible](benzene and B(a)P) are calculated in a similar way to those for non-carcinogenic chemicals with the following differences:

- the risk-specific concentration (RsC), evaluated at an incremental cancer risk of 1 in 100,000, is used in place of the reference concentration (RfC);
- the risk-specific dose (RsD), evaluated at an incremental cancer risk of 1 in 100,000, is used in place of the tolerable daily intake (TDI);

- background exposure is not considered, as guidelines are based on incremental cancer risk above background;
- exposure to carcinogens is evaluated for lifetime exposure (CCME, 1996); and,
- adults, rather than toddlers, are used as the receptor of concern in all land uses.

The soil quality guidelines calculated for benzene for the soil ingestion pathway (SQG_{SI}) are presented in Tables 2.1 to 2.4. The following equation was used to calculate the SQG_{SI}. Data for benzene in a residential land use scenario are provided as an example:

$$SQG_{SI} = \frac{RsD \times SAF \times BW \times 10^3}{SIR \times AF_G \times ET}$$

Where:

SQG_{SI}	=	human health soil quality guideline for soil ingestion (mg/kg);
RsD	=	risk-specific dose evaluated at an incremental cancer risk of 1 in 100,000 (0.00069 mg/kg-bw/day; see Table 1.1);
SAF	=	soil allocation factor (0.5; see Table 1.1);
BW	=	adult body weight (70.7 kg; see Volume 1 Table 2.4);
10^3	=	conversion factor from kg to g;
SIR	=	soil ingestion rate for the adult (0.02 g/day; see Volume 1 Table 2.4;);
AF_G	=	absorption factor for gut (1; see Table 1.1); and,
ET	=	exposure term for residential use (1; see Volume 1 Table 2.4).

Substituting these values in the above equations and rounding to 2 significant figures yields a value of 1,200 mg/kg, which is the guideline for incidental human soil ingestion of benzene in a residential setting (SQG_{SI}) (Tables 2.1 and 2.2).

DRAFT

4 ECOLOGICAL HEALTH GUIDELINES

This section describes the development of ecological health guidelines for BTEX, B(a)P, and PHC fractions F1 to F4, and provides example calculations for each of the ecological health pathways examined (*i.e.*, plant/invertebrate soil contact, soil ingestion by livestock/wildlife, protection of groundwater for aquatic life, and protection of groundwater for livestock/wildlife ingestion), where applicable. Where required, ecological exposure limits were derived for this project. Details are provided in Appendix 1.

4.1 Plant/Invertebrate Soil Contact

The soil quality guidelines calculated for the plant/invertebrate soil contact pathway (SQG_{SC}) are presented in Tables 2.1 to 2.4. SQG_{SC} for PHC fractions F1 to F4 are adopted without change from CCME (2000).

Plant, invertebrate, and micro-organism toxicity data exist for BTEX, and are summarized in Appendix I. However, significant advances have been made in the last few years in the techniques for determining the toxicity of highly volatile compounds, and a new set of protocols is available (Environment Canada, 1998a,b,c). It is not clear whether existing data are acceptable based on the Environment Canada guidelines. Accordingly, none of the existing data were used in the guideline derivation process.

A new study was commissioned for this report. The purpose of the study was to determine the toxicity of BTEX compounds to one terrestrial plant species and one earthworm species, using up to date protocols for toxicity tests with volatile compounds. A single plant species was considered acceptable for this work, because the species chosen was the most sensitive in work done for the petroleum hydrocarbon Canada-Wide Standard (CCME, 2000). The study was undertaken by ESG International (ESG, 2001), with the following scope:

- the test species were *Eisenia andrei* (earthworm) and *Agropyron dasystachyum* (early northern wheatgrass);
- earthworm tests measured 7 and 14 day mortality endpoints;
- wheatgrass tests measured seedling emergence and shoot and root length and dry and wet biomass endpoints, all at 14 days;
- Two soils were used: "Artificial" was a Coarse soil; and "Alberta Till" was a Fine soil;
- procedures were adopted to minimize loss of volatile compounds from the tests; and,
- chemical analysis was undertaken at the start of the tests to estimate the actual concentrations of BTEX compounds to which the organisms were exposed at the start of the tests.

DRAFT

A summary of the results of this study can be found in Appendix I. The derivation of the soil quality guideline for plant/invertebrate soil contact (SQG_{SC}) followed the procedure developed for other hydrocarbon compounds in the PHC CWS (CCME, 2000). This procedure is as follows:

- for each distinct test/endpoint, only the data representing a 50% effect are considered (*i.e.*, median lethal concentration (LC50) or 50% inhibition concentration (IC50));
- if tests differ only in duration, only data for the longest duration are used;
- if multiple data are available for the same chemical, endpoint and species, these data are replaced by their geometric mean;
- for natural area, agricultural, or residential land use, the SQG_{SC} was calculated as the 25th percentile of plant and invertebrate data; and,
- for commercial and industrial land use, the SQG_{SC} was calculated as the 50th percentile of plant data only.

SQG_{SC} surface soil values are calculated using the above procedure and are provided in Tables 2.1 and 2.2. SQG_{SC} values for subsoil are calculated based on management decisions in the PHC CWS (CCME, 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than the surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. In this document, subsoil guidelines for this pathway are calculated by doubling the corresponding surface soil guideline, except in cases where this would result in a concentration close to the solubility of the compound in question, in which case the corresponding surface soil guideline was adopted directly as the subsoil guideline. Subsoil guidelines are summarized in Tables 2.3 and 2.4.

4.2 Soil Ingestion by Livestock/Wildlife

The calculated soil quality guidelines for the soil ingestion by livestock/wildlife pathway (SQG_{ESI}) are presented in Tables 2.1 to 2.4. DTEDs for livestock and wildlife were developed for BTEX in Appendix 1, and are summarized in Table 1.1. DTEDs for the petroleum hydrocarbon fractions F1 to F4 were adopted directly from CCME (2000). The SQG_{ESI} were developed based on exposure to a dairy cow in the agricultural land use scenario and multiplied by a factor of 2 for the natural area land use scenario. A soil quality guideline was not developed for benzo(a)pyrene because carcinogenic endpoints are not normally considered relevant in ecological risk assessments and the non-carcinogenic toxicity of B(a)P was accounted for in the soil quality guideline derived for PHC fraction F3 (CCME, 2000).

DRAFT

The SQG_{ESI} was calculated using the following equation. Data for ethylbenzene in the natural area land use scenario is provided as an example.

$$SQG_{ESI} = \frac{0.75 \times DTED \times BW \times 1{,}000}{SIR \times BF}$$

Where: SQG_{ESI} = ecological quality guideline for soil ingestion livestock/wildlife (mg/kg);

0.75 = factor to prevent animals from being exposed to more than 75% of the DTED (unitless; CCME, 1996);

DTED = daily threshold effect dose for livestock/wildlife (2.91 mg/kg-bw/day; see Table 1.1, and Appendix I);
BW = body weight for deer (68 kg; see Volume 1 Table 2.5);
1,000 = conversion factor from kg to g;
SIR = soil ingestion rate for deer (44 g/day; see Volume 1 Table 2.5); and,
BF = bioavailability factor (1; assumed).

Substituting these values in the above equation and rounding to 2 significant figures yields a value of 3,400 mg/kg, which is the guideline for soil ingestion by wildlife (SQG_{ESI}; Tables 2.1 and 2.2).

4.3 Protection of Groundwater for Ecological Receptors

The soil quality guidelines calculated for protection of groundwater for aquatic life (SQG_{AL}), and for the protection of groundwater for livestock/wildlife watering (SQG_{GI}) were calculated for BTEX and PHC fractions F1 and F2, and are presented in Tables 2.1 to 2.4. The equations below were used for all the above compounds. The BTEX guidelines were calculated using the chemical-specific parameters in Table 1.1.

The F1 and F2 guidelines were calculated separately for each of the sub-fractions, using chemical-specific parameters in Table 1.2. The guidelines for each sub-fraction were then combined using the same procedure as described in Section 3.6.1 for the protection of potable groundwater pathway. The only difference between the F1 and F2 guidelines calculated here, and those calculated in the Canada-Wide Standard is the substitution of the Alberta-specific recharge value[illegible] m/year and 0.012 m/year for Coarse and Fine soils, respectively, see Table 2.1 of [illegible] for the Canada-Wide Standard value.

Values for SQG_{AL} and SQG_{GI} were not calcul[illegible] B[illegible]3, [illegible]4 becau[illegible] these compounds are only sparingly soluble in water, and th[illegible] you[illegible] not[illegible] ex[illegible]ct [illegible]to[illegible] ve an appreciable concentration in discharging groundwater.

The SQG_{AL} and SQG_{GI} were cal[illegible]ated usi[illegible] th[illegible]lowing equations. As noted in Volume 1, the calculation of these guidelines is b[illegible]d [illegible] th[illegible]ssociated water quality guideline and a dilution factor calculated for each of four process[illegible]

1. partitioning from soil to leachate;
2. transport of leachate from base of contamination to water table;
3. mixing of leachate and groundwater; and,
4. groundwater transport downgradient to surface water receptor.

DRAFT

The SQG_{AL} guideline for ethylbenzene in Coarse soil is provided as an example:

$$SQG_{AL} = C_{AL}DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

where:

SQG_{AL}	=	soil quality guideline protective of groundwater for aquatic life, (mg/kg);
C_W	=	water quality guideline for aquatic life (0.090 mg/L; see Table 5.1);
DF	=	overall dilution factor (878 L/kg);
DF1	=	dilution factor 1, (2.81 L/kg);
DF2	=	dilution factor 2, (1.00);
DF3	=	dilution factor 3, (5.83); and,
DF4	=	dilution factor 4, (53.5).

Substituting these values in the above equations and rounding to 2 significant figures yields 79 mg/kg, which is the guideline for protection of freshwater aquatic life for ethylbenzene in Coarse soil (SQG_{AL}) (Tables 2.2 and 2.4). Note that the corresponding SQG_{GI} values for livestock and wildlife watering are calculated by multiplying the applicable water quality guideline (Table 5.1) by the same dilution factor. The calculations for the individual dilution factors are reproduced below.

4.3.1 Dilution Factor 1

Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This "dilution factor" represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in soil water (*i.e.*, as leachate), and contaminant present as soil vapour. DF1 is calculated using the following equation:

DRAFT

$$DF1 = K_{oc} f_{oc} + \frac{(\theta_w + H' \theta_a)}{\rho_b}$$

where:

DF1	=	dilution factor 1 (L/kg);
K_{oc}	=	organic carbon partition coefficient (537 mL/g; see Table 1.1);
f_{oc}	=	fraction organic carbon (0.005 g/g; see Volume 1 Table 2.1);
θ_w	=	water filled porosity (0.119; see Volume 1 Table 2.1);
H′	=	dimensionless Henry's Law constant (0.358; Table 1.1);
θ_a	=	air filled porosity (0.281; see Volume 1 Table 2.1); and,
ρ_b	=	dry soil bulk density (1.7 g/cm^3; see Volume 1 Table 2.1).

Substituting these values in the above equations yields a value for DF1 of 2.81 L/kg.

4.3.2 Dilution Factor 2

Dilution factor 2 (DF2) is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. DF2 takes the value 1.00 (*i.e.,* no dilution) for generic guidelines because it is assumed at Tier 1 that the contaminated soil extends down to the water table.

4.3.3 Dilution Factor 3

Dilution factor 3 (DF3) is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing zone thickness is calculated as being due to two processes: i) mixing due to dispersion, and ii) mixing due to infiltration rate. The equations used are as follows:

$$DF3 = 1 + \frac{Z_d V}{IX}$$

$$Z_d = r + s$$

$$r = 0.01X$$

$$s = d_a \left\{ 1 - exp\left(\frac{-2.17 XI}{V} \right) \right\}$$

$$V = \frac{Ki}{}$$

DRAFT

where:

DF3	=	dilution factor (dimensionless);
Z_d	=	average thickness of mixing zone (0.181 m; calculated above);
V	=	Darcy velocity in groundwater (16 m/year);
I	=	infiltration rate (0.060 m/year; see Volume 1 Table 2.1);
X	=	length of contaminated soil (10 m; see Volume 1 Table 4.1);
r	=	mixing depth due to dispersion (0.10 m; calculated above);
s	=	mixing depth due to infiltration rate (0.081 m; calculated above);
d_a	=	unconfined aquifer thickness (5 m; see Volume 1 Table 4.1);
K	=	aquifer hydraulic conductivity (320 m/year; see Volume 1 Table 2.1); and,

i = lateral hydraulic gradient in aquifer (0.05; see Volume 1 Table 3.2).

Substituting these values in the above equations yields a value for DF3 of 5.83.

4.3.4 Dilution Factor 4

Dilution factor 4 (DF4) accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1) downgradient of the source. DF4 was calculated using the following equations:

$$DF4 = \frac{4}{exp(A) \times erfc(B) \times [erf(C) - erf(D)]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$B = \frac{x - vt\left(1 + \frac{4L_s D_x}{v}\right)^{1/2}}{2(D_x vt)^{1/2}}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.}{t_i} \times \ldots (0.07a)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

DRAFT

where:

DF4	=	dilution factor 4 (dimensionless);
erf	=	the error function;
erfc	=	the complementary error function;
A	=	dimensionless group A (-3.89; calculated above);
B	=	dimensionless group B (-15.8; calculated above);
C	=	dimensionless group C (7.50; calculated above);
D	=	dimensionless group D (-7.50; calculated above);
x	=	distance to source (10 m; see Volume 1 Table 4.1);
D_x	=	dispersivity in the direction of groundwater flow (1.0 m; calculated);
L_s	=	decay constant (1.79 $year^{-1}$; calculated above);
v	=	velocity of the contaminant (3.22 m/year; calculated above);
t	=	time since contaminant release (100 years; see Volume 1 Table 4.1);
y	=	distance to receptor perpendicular to groundwater flow (0 m; see Volume 1 Table 4.1);
Y	=	source width (30 m; see Volume 1 Table 4.1);
D_y	=	dispersivity perpendicular to the direction of groundwater flow (0.10 m; calculated above);
$t_{1/2s}$	=	decay half-life of chemical in aquifer (0.312 years; see Table 1.1);
d	=	water table depth (3 m; see Volume 1 Table 4.1);
V	=	Darcy velocity in groundwater (16 m/year; calculated);
θ_t	=	total soil porosity (0.40; see Volume 1 Table 2.1);
R_s	=	retardation factor in saturated zone (12.4; ca above);
ρ_b	=	dry soil bulk density (1.7 g/cm^3; see V ble 2.1);
K_{oc}	=	organic carbon partition coefficien 7 mL/g e Table 1.1); and,
f_{oc}	=	fraction organic carbon (0. g/g; olum Table 2.1).

Substituting these values in the above e vie a v e D of 53.5.

DRAFT

5 WATER QUALITY GUIDELINES

Two types of water quality guideli defined in this project.

Exposure Point water quality guidelines are applied to the water to which a receptor is actually exposed, and are used in this project as targets for calculating soil guidelines protective of various groundwater uses. Exposure Point water quality guidelines are summarized in Table 5.1, and are discussed in more detail in Section 5.1 below.

Groundwater quality guidelines provide a reference value to allow a determination of the quality of groundwater, and, for some water uses, take into account the effect of certain transport processes that

may occur between the point of groundwater measurement and the receptor. Groundwater quality guidelines are summarized in Table 5.2, and are discussed in more detail in Section 5.2 below.

5.1 Exposure Point Water Quality Guidelines

Exposure point water quality guidelines were compiled or calculated for BTEX and for PHC fractions F1 and F2 to protect the following water uses:

- human drinking water;
- freshwater aquatic life;
- livestock watering; and,
- wildlife watering.

Exposure point water quality guidelines are summarized in Table 5.1. Guidelines for F3, F4, and BaP are not required, since the low aqueous solubility and high K_{ow} of these hydrocarbons makes it unlikely that exposure to dissolved concentrations of these chemicals in water will be significant.

Where available and appropriate, CCME (1999) water quality guidelines are used. Otherwise, guidelines were calculated for this project. Example calculations are provided below.

5.1.1 Human Drinking Water

Human drinking water quality guidelines are summarized in Table 5.1. BTEX guidelines are available from Health Canada (1996b). Guidelines for F1 and F2 were calculated using the formula below. The guideline for PHC fraction F1 is calculated as an example.

DRAFT

$$Drinking\ Water\ Guideline\ (mg/L) = \left(\frac{BW \times TDI}{IR_w \times BIO_o} \right)$$

Where:

BW	=	receptor body weight (16.5 kg (child, 0.5-4 years); see Volume 1 Table 2.4);
TDI	=	tolerable daily intake for F1 (0.168 mg/kg-bw/day; see below);
IR_w	=	drinking water ingestion rate (0.6 L/day (child, 0.5-4 years); see Volume 1 Table 2.4); and,
BIO_O	=	oral bioavailability (gut absorption factor) (1.0; see Table 1.3).

Substituting these values in the above equations and rounding to 2 significant figures yields a drinking water guideline for PHC fraction F1 of 4.6 mg/L (Table 5.1). The calculation for TDI is reproduced below.

The tolerable daily intake for each fraction (F1 and F2) was calculated from the tolerable daily intake (TDI) for each sub-fraction as published by TPHCWG (1997), and the relative abundance of each sub-fraction in the fraction (Table 1.2), using the following formula:

$$\textit{Tolerable Daily Intake for PHC Fraction}\ (mg/kg-bw/day) = \frac{1}{\sum_i \frac{F_i}{TDI_i}}$$

where:

F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,

TDI_i = the tolerable daily intake of sub-fraction i (mg/kg-bw/day; see Table 1.2).

$$\textit{Tolerable Daily Intake for F1} = \frac{1}{\left(\frac{0.55}{5}\right)+\left(\frac{0.36}{0.1}\right)+\left(\frac{0.09}{0.04}\right)} = 0.168\ mg/kg-bw/day$$

5.1.2 Freshwater Aquatic Life

Exposure point water quality guidelines (AENV, 1999) for freshwater aquatic life are summarized in Table 5.1. Guidelines are available for benzene, toluene, and ethylbenzene and xylenes. A guideline for xylenes was derived using the protocol published in CCME (1999). Details are included in Appendix I. Guidelines for F1 and F2 were calculated using the formula below. The freshwater aquatic life guideline for F1 is provided as an example.

DRAFT

$$\textit{Exposure Point Aquatic Life Guideline for Fraction}\ (mg/L) = \frac{1}{\sum_i \frac{F_i}{WQG_i}}$$

where:

F_i = the assumed proportion of the fraction made up of sub-fraction i (dimensionless; see Table 1.2); and,

WQG_i = the water quality guideline for sub-fraction i (mg/L; see Table 1.2).

$$\textit{Exposure Point Aquatic Life Guideline for F1} = \frac{1}{\left(\frac{0.55}{0.0465}\right)+\left(\frac{0.36}{0.0076}\right)+\left(\frac{0.09}{0.14}\right)} = 0.017\ mg/L$$

5.1.3 Livestock and Wildlife Watering

Exposure point water quality guidelines for livestock/wildlife watering are summarized in Table 5.1. Livestock watering guidelines are available (CCME, 1999) for toluene, and ethylbenzene. However, these guidelines are based on the human smell and taste threshold for these chemicals. This project developed health-based livestock/wildlife watering guidelines for BTEX and F1 and F2. Watering guidelines for livestock and wildlife are calculated using parameters for dairy cows and mule deer, respectively (parameters available in Volume 1, Table 2.5). The wildlife watering guideline for F1 was calculated as an example:

$$Livestock\,/\,Wildlife\ Watering\ Guideline\ (mg\,/\,L) = \left(\frac{BW \times DTED}{IR_w \times BIO_o}\right)$$

Where:

BW	=	body weight for mule deer (68 kg; see Volume 1 Table 2.5);
DTED	=	daily threshold effect dose for F1 (9.74 mg/kg-bw/day; Table 1.3);
IR_W	=	drinking water ingestion rate for mule deer (4.4 L/day; see Volume 1 Table 2.5); and,
BIO_O	=	oral bioavailability (gut absorption factor) (1.0; see Table 1.3).

Substituting these values in the above equation and rounding to 2 significant figures yields a wildlife watering guideline for PHC fraction F1 of 150 mg/L (Table 5.1).

5.2 Groundwater Quality Guidelines

Groundwater water quality guidelines are summarized in Table 5.1 and were derived from exposure point water quality guidelines to protect the groundwater as noted above. The procedure for each water use is discussed below.

DRAFT

5.2.1 Human Drinking Water

The groundwater quality guidelines for human drinking water are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a drinking water well could potentially be drilled anywhere within a former upstream oil and gas facility. However, the groundwater quality guidelines for human drinking water need only be applied to groundwater that is in or potentially in hydraulic contact with a Domestic Use Aquifer, as defined by AENV (2001). Guidance on determining whether contaminated groundwater is in hydraulic contact with a Domestic Use Aquifer is provided in Section 3.6.4.

5.2.2 Livestock Watering

The groundwater quality guidelines for livestock watering are adopted directly from the corresponding exposure point water quality guidelines, based on the assumption that a dugout or water well for livestock watering could potentially be installed anywhere within a former upstream oil and gas facility. The groundwater quality guideline for livestock watering need only be applied where the land use is agricultural.

5.2.3 Freshwater Aquatic Life and Wildlife Watering

Two cases are considered for these two water uses. Separate guidelines are derived for groundwater less than 10 m from the nearest surface water body, and for groundwater more than 10 m from the nearest surface water body.

Groundwater Less Than 10 m From The Nearest Surface Water Body

For groundwater less than 10 m from the nearest surface water body, the exposure point water quality guidelines are adopted directly as groundwater quality guidelines. Note that no groundwater guidelines are provided in this category for F1 and F2, as the available data are not considered appropriate.

Groundwater More Than 10 m From The Nearest Surface Water Body

For groundwater more than 10 m from the nearest surface water body, the guidelines ("the >10 m guidelines") are less stringent than the corresponding exposure point water quality guidelines. These less stringent guidelines are based on the assumption that groundwater transport processes will result in a decrease in concentration between the point of measurement and a receptor coming in contact with or drinking from a surface water body.

The >10 m guidelines are calculated by dividing the corresponding exposure point water quality guideline by the dilution factor from the saturated zone transport model used in the calculation of the soil quality guideline for protection of ecological receptors (i.e., DF from Section 4.3.4). All the same parameters are used as in the calculation in Section 4.3.4, including the assumed 10 m offset. A set of guidelines for Coarse soil was calculated using the generic soil parameters for Coarse soil (Table 5.2). However, no valid guidelines could be calculated for the Fine soil, because the model does not predict that hydrocarbon contamination in groundwater will travel as much as 10 m in this material. Accordingly no guidelines are required for groundwater more than 10 m from a surface water body in Fine soil for freshwater aquatic life or wildlife watering.

The groundwater quality guideline for protection of freshwater aquatic life is applicable to all land uses. The groundwater quality guideline for protection of wildlife watering is only applicable to natural area or agricultural land use.

DRAFT

6 REFERENCES

AENV (Alberta Environmental Protection), 1999. Surface Water Quality Guidelines for Use in Alberta. Environmental Sciences Division. November 1999.

AENV(Alberta Environment), 2001. Alberta Groundwater Quality Objectives (*in preparation*).

ATSDR (Agency for Toxic Substances and Disease Registry), 1999. Toxicological Profile for Ethylbenzene. U.S. Department of Health and Human Services. U.S. Public Health Services.

BCMELP (British Columbia Ministry of Environment, Lands and Parks), 1996. Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites. BC Ministry of Environment, Lands and Parks.

CCME (Canadian Council of Ministers of the Environment), 1996. A Protocol for the Derivation of Environmental and human Health Soil Quality Guidelines. Canadian Council of Ministers of The Environment. The National Contaminated Sites Remediation Program. March, 1996. CCME-EPC-101E.

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg.

CCME (Canadian Council of Ministers of the Environment), 2000. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale, Supporting Technical Document. December, 2000.

Environment Canada, 1998a. Development of Plant Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 75 (Appendices).

Environment Canada, 1998b. Development of Earthworm Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 52 (Appendices).

Environment Canada, 1998c. Development of Reproduction Toxicity Test with *Onychiurus folsomi* for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 250 (Appendices).

ESG International Inc., 2001. Toxicity Assessment of BTEX Compounds. Report prepared for Dr. Ted Nason, Alberta Environment, Environmental Science Division. June 2001.

Health Canada, 1992. Toluene: Priority Substances List Assessment Report No. 4. Health and Welfare Canada. Environment Canada. Ottawa, ON. En40-215/4E.

Health Canada, 1993. Xylenes: Priority Substances List Assessment Report. Health Canada. Environment Canada. Ottawa, ON. En40-215/22E.

Health Canada, 1996a. Health-Based Tolerable Daily Intakes/Concentrations and Tumorigenic Doses/Concentrations for Priority Substances. Health Canada, Environmental Health Directorate, Health Protection Branch. 96-EHD-194.

DRAFT

Health Canada, 1996b. Guidelines for Canadian Drinking Water Quality, Sixth Edition. Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial Committee on Environmental and Occupational Health. Ref. 96-EHD-196.

TPHCWG (Total Petroleum Hydrocarbon Criteria Working Group), 1997. Total Petroleum Hydrocarbon Criteria Working Group Series (4 Volumes).

US EPA (United States Environmental Protection Agency), 2001. IRIS online database. http://www.epa.gov/iris/

DRAFT

APPENDIX I

ECOLOGICAL TOXICITY DATA

DRAFT

A1. INTRODUCTION

This Appendix provides background information on the toxicity data that were used to derive benzene, toluene, ethylbenzene, and xylenes (BTEX) exposure limits for ecological receptors. Exposure limits for the four petroleum hydrocarbon (PHC) fractions F1 to F4 were adopted directly form CCME (2000), and are summarized in Tables 1.2 and 1.3 of the main text. BTEX exposure limits for three groups of receptors are discussed:

- Plants, soil invertebrates, and micro-organisms (Section 2);
- livestock and wildlife (Section 3); and,
- freshwater aquatic life (Section 4).

A2. PLANTS, SOIL INVERTEBRATES AND MICRO-ORGANISMS

Data on the toxicity of the chemicals of concern to terrestrial plants, invertebrates and microorganisms are required to assess the ecological soil contact pathway, and to calculate the soil quality guideline for soil contact (SQG_{SC}). Existing data are reviewed in Section 2.1 below. These data are not used in the guideline derivation process, due to uncertainties in the protocols used for determining the toxicity of volatile compounds in soil. A new study was commissioned for this report. This work is described in Section 2.2, and is used as the basis for guideline derivation of the ecological soil contact pathway.

A2.1 Review of Existing Data

In this Section, the existing data on the toxicity of the chemicals of concern to terrestrial plants, invertebrates and microorganisms are reviewed. Significant advances in the techniques for determining the toxicity of highly volatile compounds in soils have been made in the last few years, and a new set of protocols is available (Environment Canada, 1998a,b,c). It is not clear whether the protocols used to obtain the existing data were acceptable based on the criteria noted above. Accordingly, none of these data are used in the guideline derivation process, and they are included for completeness only.

DRAFT

A2.1.1 Benzene

Existing benzene data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 42 and 280 mg/kg for the two soils tested. The NOEC and LOEC for growth (*Eisenia foetida*) were 4% and 8% (dry weight), respectively, for a 4 mm layer of sludge applied to the surface of a silt loam (Hartenstein, 1982). The NOEC for survival was 8%

(Hartenstein, 1982). In two filter paper contact tests, the LC_{50} for the earthworm *Eisenia foetida* were 98 µg/cm^2 (Neuhauser *et al.*, 1985) and 6.15 µg/kg (Callahan *et al.*, 1994). An air concentration of 10,000 – 210,000 mg/m^3 is reportedly lethal to insects (Miller *et al.*, 1976).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 22 and 26 mg/kg for radishes and 7.0 and 73 mg/kg for lettuce. The reported EC_{25} values for root elongation were 14 and 127 mg/kg for radishes and 30 and 56 mg/kg for lettuce. Lettuce (*Lactuca sativa*) germination EC_{50} in agar was greater than 78 mg/L (solubility limit for benzene) (Reynolds, 1989).

An air concentration of 10,000 mg/m^3 is acutely toxic to plants (Miller *et al.*, 1976). The LC_{50} (benzene vapours) for runner bean (*Phaseolus multiflorus*) and parsnip leaves was reported to be 154 x 10^5 and 269 x 10^5 mol/L, respectively (Ivens, 1952). The EC_{50} (benzene vapours) for tobacco (*Nicotiana tabacum*) pollen germination was 36.5 mg/L (Schubert *et al.*, 1995).

An 8-hour exposure to benzene vapours at 1.2 mM/L resulted in trace injury (as measured by leaf damage) to barley plants. A ½-hour and 1-hour exposure to vapours at 2.7 mM/L resulted in 95% and 100% injury, respectively to barley plants. A 2-hour exposure at 2.7 and 3.0 mM/L resulted in 0% and 10% injury, respectively to carrot plants (Currier and Peoples, 1954). A 2-hour exposure to benzene vapours at 3.2 x 10^{-4} M resulted in 100% injury (as measured by leaf damage) in barley and tomato plants and 95% injury in carrot plants. A ¼-hour exposure resulted in 60% injury in barley, 80% injury in tomato plants and 0% injury in carrot plants. Benzene vapours at 2.2 x 10[illegible] sulted in 2% injury in barley following a ¼-hour exposure and 25% injury following a 4[illegible]ure. Vapours at 6.4 x 10^{-4} M resulted in 40% injury in barley following a ¼-hour expos[illegible] and 100[illegible] injury following a ½-hour exposure (Currier, 1951).

DRAFT

Soil Microorganisms

Microbial respiration was not affe[illegible]en[illegible]vels[illegible]0[illegible]g/kg in a silt loam but a transient decrease in microbial respiration di[illegible]cct[illegible]n[illegible]a[illegible]lo[illegible]a at [illegible],000 mg/kg (Walton *et al.*, 1989). No effects on soil microorganisms occ[illegible]ed [illegible]a [illegible] c[illegible]ntration of 100 mg/kg (Anderson *et al.*, 1991). Ammonia oxidation EC_{50} by the so[illegible]pa[illegible]ium *Nitrosomonas europaea* was reported to be 132 uM (soil solution) (Keener and Arp, 19[illegible]

A2.1.2 Toluene

Existing toluene data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 77 and 11 mg/kg for the two soils tested. The earthworm

(*Eisenia foetida*) NOEC for appearance was reported to be between 15 and 50 mg/kg, while the LC_{50} was between 150 and 280 mg/kg (Sloof and Blokzijl, 1988). Both the LC_{50} and NOEC for earthworm (*Eisenia foetida*) survival were between 222 and 400 mg/kg. The NOEC for reproduction was between 71 and 222 mg/kg (Vonk *et al.*, 1986). The NOEC and LOEC for growth (*Eisenia foetida*) were 0.1% and 1.0% (dry weight), respectively for a 4 mm layer of sludge applied to the surface of a silt loam. The NOEC and LOEC for survival were 1.0 and 4%, respectively (Hartenstein, 1982).

In two filter paper contact test with the earthworm *Eisenia foetida*, the LC_{50} was reported to be 75 µg/cm^2 (Neuhauser *et al.*, 1985) and 4.18 µg/kg (Callahan *et al.*, 1994). Nematode abundance and arthropod activity were not affected at 20 µg/mL (soil solution) (Fuller *et al.*, 1997).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 7.1 mg/kg for radishes and 8.6 and 9.8 mg/kg for lettuce (Note: the second EC_{25} values for radishes could not be calculated). The reported EC_{25} values for root elongation were 14 and 7.0 mg/kg for radishes and 3.7 and 5.9 mg/kg for lettuce. Plant growth inhibition and chlorosis occurred at a soil concentration of 1,000 mg/kg (wet weight) (Sloof and Blokzijl, 1988). Lettuce (*Lactuca sativa*) shoot growth EC_{50} was >1,000 mg/kg (Hulzebos *et al.*, 1993).

Corn and soybean germination NOEC = 20,000 mg/kg in clay. Soybean shoot weight NOEC and LOEC (32% reduction) = 2,000 and 20,000 mg/kg, respectively in clay. C[illegible]hoot weight LOEC (30% reduction) = 200 mg/kg. Soybean germination NOEC and L[illegible] reduction) = 200 and 2,000 mg/kg, respectively in a sandy loam at pH 4. Corn ge[illegible]nation N[illegible]EC and LOEC (86% reduction) = 2,000 and 20,000 mg/kg, respectively in a sa[illegible]loam[illegible]4. S[illegible]bea[illegible] corn and fescue germination was not affected at 20,000 mg/kg i[illegible]ndy [illegible]a at [illegible]6. Soyb[illegible]n shoot weight LOEC (40% reduction) = 200 mg/kg in a sand[illegible] loa[illegible]at [illegible]6. C[illegible]sh[illegible] weight NOEC and LOEC (68% reduction) = 2,000 and 20,000 m[illegible]pe[illegible] in [illegible]l[illegible]n at pH 6. Fescue shoot weight NOEC and LOEC (22% reduction[illegible] = 2,[illegible]0 [illegible]0[illegible]mg/kg, respectively in a sandy loam at pH 6 (Overcash *et al.*, 1982).

DRAFT

Seed germination was not affected[illegible]0 µg/mL (soil solution) (Fuller *et al.*, 1997). Plant growth inhibition and chlorosis occurred at a water concentration of 500 mg/L (Sloof and Blokzijl, 1988). Lettuce (*Lactuca sativa*) shoot growth EC_{50} was 16 mg/L (solution) (Hulzebos *et al.*, 1993).

The LC_{50} for runner bean (*Phaseolus multiflorus*) and parsnip leaves was 47.5 x 10^5 and 96.7 x 10^5 mol/L, respectively (Ivens, 1952). The EC_{25} and EC_{50} (vapours) for tobacco (*Nicotiana tabacum*) pollen germination were 9.8 and 28.9 mg/L (Schubert *et al.*, 1995). A 2-hour exposure to toluene vapours at 1.3 x 10^{-4} M resulted in 100% injury (as measured by leaf damage) in barley and tomato plants and 98% injury in carrot plants. A ¼-hour exposure resulted in 70% injury in barley, 85% injury

in tomato plants and 0% injury in carrot plants. Toluene vapours at 0.69 x 10^{-4} M resulted in 2% injury in barley following a ¼-hour exposure and 50% injury following a 2-hour exposure. Vapours at 4.9 x 10^{-4} M resulted in 100% injury in barley following a ¼-hour exposure (Currier, 1951).

Soil Microorganisms

The NOEC for microbial respiration and ammonification ranged from 100 – 1,300 mg/kg while the NOEC for nitrification was <26 mg/kg (Sloof and Blokzijl, 1988). Vonk *et al.* (1986) reported the NOEC for microbial respiration to be between 300 – 1,000 mg/kg and the NOEC for nitrification to be <20 mg/kg. A transient increase in microbial respiration occurred at 1,000 mg/kg in a silt loam while a transient decrease occurred in a sandy loam (Walton *et al.*, 1989). A concentration of 25 mg/kg had no effect on microbial respiration (Kirchmann *et al.*, 1991) and no effects on soil microorganisms were reported at a soil concentration of 100 mg/kg (Anderson *et al.*, 1991).

There was no effect on ammonification or soil denitrification at 20 µg/mL (soil solution) (Fuller and Scow, 1997). The NOEC and LOEC for toxicity to toluene degrading microorganisms was 625 and 1,000 µg/mL (soil solution), respectively (Mu and Scow, 1994). The ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was 106 uM (soil solution) (Keener and Arp, 1994). Microbial diversity NOEC and LOEC were reported to be 60 and 100 µg/mL (soil solution), respectively (Fuller *et al.*, 1997). Total culturable heterotrophs were slightly reduced at 200 µg/mL (soil solution) (Fuller *et al.*, 1997). Ammonia oxidation NOEC and LOEC were 20 and 60 µg/mL (soil solution), respectively while the nitrite oxidation NOEC and LOEC were 60 and 100 µg/mL (soil solution), respectively (Fuller and Scow, 1996).

A2.1.3 Ethylbenzene

Existing ethylbenzene data are reviewed below.

DRAFT

Invertebrates

Environment Canada (1995) conduc[illegible] experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported [illegible] for the two soils tested. In two filter paper contact test, the earthworm (*Eisenia foetida*) LC_{50} [illegible]47 µg/cm^2 (Neuhauser *et al.*, 1985) and 4.93 µg/kg (Callahan *et al.*, 1994).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 16 and 7.0 mg/kg for radishes and 7.0 and 5.0 mg/kg for lettuce. The reported EC_{25} values for root elongation were 31 and 70 mg/kg for radishes and 5.8 and 24 mg/kg for lettuce. The LC_{50} (ethylbenzene vapours) for runner bean (*Phaseolus multiflorus*) and parsnip leaves was 25.5 x 10^5 and 45.2 x 10^5 mol/L, respectively (Ivens, 1952).

Soil Microorganisms

The ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was 143 uM (soil solution) (Keener and Arp, 1994).

A2.1.4 Xylenes

Existing xylenes data are reviewed below.

Invertebrates

Environment Canada (1995) conducted a series of experiments on earthworms (*Eisenia foetida*). The 7-day LC_{25} values were reported to be 48 and 63 mg/kg for the two soils tested. The LC_{50} for the grain weevil (*Calandra granaria*) was 31 g/m^3 for *o*-xylene and 48 g/m^3 for *p*-xylene (Miller *et al.*, 1976). A dose of 0.002 mL was toxic to the housefly (*Musca domestica*) (Miller *et al.*, 1976).

Plants

Environment Canada (1995) conducted a series of experiments on radish (*Raphanus sativa*) and lettuce (*Lactuca sativa*). The reported EC_{25} values for seedling emergence were 14 and 49 mg/kg for radishes and 1.5 and 8.1 mg/kg for lettuce. The reported EC_{25} values for root elongation were 1.2 and 0.10 mg/kg for radishes and 0.5 and 0.18 mg/kg for lettuce. Lettuce (*Lactuca sativa*) shoot growth EC_{50} was reported to be >1,000 mg/kg for o-xylene (Hulzebos *et al.*, 1993).

Sugar beet root growth was reduced by 31.5%, 29.1% and 23.6% when exposed to a 100, 200 and 500 mg/L solution, respectively (Allen *et al.*, 1961). Lettuce (*Lactuca sativa*) root growth EC_{50} was reported to be between 1 and 3.2 mg/L (solution) for *o*-xylene (Hulzebos *et al.*, 1993). Germination of beans, oats, lettuce, and radishes were affected by 0.1 mg/L in water (Miller *et al.*, 1976). There were no detectable signs of injury or loss of crop yield (alfalfa, ash[illegible]pes, tomatoes, dwarf corn and beans) when xylenes was applied at 370, 740 [illegible] mg/[illegible] (Brunand Kelly, 1974).

The LC_{50} (xylenes vapours) for rutabaga (*Brassica napobrassica*) and parsnip leaves was 22.9 x 10^5 and 37.7 x 10^5 mol/L, respectively, for *m*-xylene and 18.4 x 10^5 and 27.6 x 10^5 mol/L, respectively for *o*-xylene (Ivens, 1952). The EC_{50} (vapour) for tobacco (*Nicotiana tabacum*) pollen germination was 17.1 mg/L (Schubert *et al.*, 1[illegible]). A 4-hour exposure to xylene vapours at 0.46 x 10^{-4} M resulted in 98% injury (as measured by leaf damage) in barley, 95% injury in tomato plants and 25% injury in carrot plants. A ¼-hour exposure resulted in 75% injury in barley, 40% injury in tomato plants and 0% injury in carrot plants. Xylene vapours at 0.20 x 10^{-4} M resulted in 2% injury in barley following a 2-hour exposure and 80% injury following a 4-hour exposure. Vapours at 2.4 x 10^{-4} M resulted in 95% injury in barley following a ¼-hour exposure and 100% injury following a 1-hour exposure (Currier, 1951).

Soil Microorganisms

DRAFT

Microbial respiration was not affected at 1,000 mg/kg in a silt loam but a transient decrease did occur in a sandy loam (Walton *et al.*, 1989). No effects on soil microorganisms were reported at a soil concentration of 100 mg/kg *p*-xylene (Anderson *et al.*, 1991). Ammonia oxidation was reduced by >90% at 100 µg/mL (soil solution) (Hansson *et al.*, 1991) and the ammonia oxidation EC_{50} by the soil bacterium *Nitrosomonas europaea* was 74 uM (soil solution) (Keener and Arp, 1994).

A2.2 New Data

A new study was commissioned to determine the toxicity of BTEX compounds to one plant species and one terrestrial earthworm species, using up to date protocols for toxicity tests with volatile compounds (ESG, 2001). A single plant species was considered acceptable for this work, because the species chosen was the most sensitive species in work done for the petroleum hydrocarbon Canada-Wide Standard (CCME, 2000). The study was undertaken by ESG International, with the following scope:

- test species were *Eisenia andrei* (earthworm) and *Agropyron dasystachyum* (early northern wheatgrass);
- earthworm tests measured 7 and 14 day mortality endpoints;
- wheatgrass tests measured seedling emergence, shoot and root length and dry and wet biomass endpoints, all at 14 days;
- Two soils were used: "Artificial Soil" was a Coarse soil; and "Alberta Till" was a Fine soil;
- procedures were adopted to minimize loss of volatile compounds from the tests; and,
- chemical analysis was undertaken at the start of the tests to estimate the actual concentrations of BTEX compounds to which the organisms were exposed at the start of the

The results of the ESG (2001) study for Fine and Coarse soils are summarized in Tables A-1 and A-2, respectively. As noted in Section 2.1, none of the existing BTEX toxicity data were used for guideline derivation, due to uncertainties in the protocols followed. Accordingly, the data in Tables A-1 and A-2 were used as the basis for guideline derivation.

The derivation of the soil quality guidelines for protection of environment (SQG_{SC}) followed the procedure developed for other hydrocarbon compounds in the CWS (CCME, 2000). This procedure was as follows:

- for each distinct test/endpoint, only the data representing a 50% effect are considered (*i.e.*, median lethal concentration (LC50) or 50% inhibition concentration (IC50));
- if tests differ only in duration, only data for the longest duration are used;
- if multiple data are available for the same chemical, endpoint and species, these data are replaced by their geometric mean;
- for natural area, agricultural, or residential land use, the SQG_{SC} was calculated as the 25th percentile of plant and invertebrate data; and,
- for commercial and industrial land use, the SQG_{SC} was calculated as the 50th percentile of plant data only.

DRAFT

The 25th percentile of plant and invertebrate data and the 50th percentile of plant data are included in Tables A-1 and A-2. These numbers are adopted as the SQG_{SC} guideline values for surface soil (see Tables 2.1 and 2.2 in this report).

SQG_{SC} values for subsoil are calculated based on the PHC CWS (CCME, 2000). In the PHC CWS, subsoil guidelines were between 2 and 6 times greater than the surface soil guidelines, based on the lower biological activity levels at subsoil depths, but also taking into account other considerations such as aesthetics, safety, and underground infrastructure. In this document, subsoil guidelines for this pathway are calculated as twice the corresponding surface soil guideline, except in cases where this would result in a pore water concentration close to the solubility of the compound in question, in which case the corresponding surface soil guideline was adopted directly as the subsoil guideline. Subsoil guidelines are summarized in Tables 2.3 and 2.4 of this report.

DRAFT

A3. LIVESTOCK/WILDLIFE

Two ecological pathways involving the protection of livestock/wildlife are considered in this project. The pathways are soil ingestion and protection of groundwater for ingestion. Daily threshold effects dose (DTED) values for BTEX were developed as toxicological limits for these pathways. DTED values for BTEX are summarized in Table 1.1 in the main text. DTED values for the four PHC fractions are adopted directly form CCME (2000) and are summarized in Table 1.3. A DTED is defined as a dose level below which adverse effects are not expected in a receptor.

DTEDs for livestock or wildlife have not generally been developed by regulatory agencies. However, development of the DTED follows a similar process as that for the development of a human limit and, thus, can be based on the same experimental study. Therefore, in the calculations below, the DTED is based on the same study that is used by the regulatory agencies for the human exposure limit.

A3.1 Benzene

The oral DTED for benzene applied in this project (0.08 mg/kg-bw/day), was derived based on the reported LOAEL (Lowest-Observed-Adverse-Effect-Level) from a study by Hsieh *et al.* (1988). Mice were exposed to benzene in drinking water at doses ranging from 0 to 180 mg/kg-bw/day for 28 days (water concentrations ranged from 0 to 790 mg/L). The reported LOAEL, based on hematological anemia and immunological effects, was 8 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED\ (benzene) = \frac{8}{10} = 0.08 \text{ mg/kg-bw/day}$$

DRAFT

A3.2 Toluene

The oral DTED for toluene applied in this project (4.46 mg/kg-bw/day), was derived based on the reported LOAEL from a study by the National Toxicology Program (1989). Rats were orally gavaged with doses ranging from 0 to 5,000 mg/kg in corn oil for 13 weeks (5 days/week). The reported LOAEL, based on organ weight and histopathologic changes in the liver and kidney, was 625 mg/kg-bw/day. When adjusted for a continuous exposure (*i.e.*, to 7 days/week from 5 days/week), the LOAEL becomes 446 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED\ (toluene) = \frac{625 \times (5/7)}{100} = 4.46 \text{ mg/kg} - \text{bw/day}$$

A3.3 Ethylbenzene

The oral DTED for ethylbenzene applied in this project (2.91 mg/kg-bw/day), was derived based on the reported LOAEL from a study by Wolf *et al.* (1956). Rats were orally gavaged with doses ranging from 14 to 680 mg/kg in olive oil for 182 days (5 days/week). The reported LOAEL, based on histopathologic changes in the liver and kidney, was 408 mg/kg-bw/day. When adjusted for a continuous exposure (*i.e.*, to 7 days/week from 5 days/week), the LOAEL becomes 291 mg/kg-bw/day. A 100-fold uncertainty factor was applied, based on a 10-fold factor to account for the use of a LOAEL from a less than chronic duration study, and a further 10-fold factor to account for the uncertainties in extrapolating from one species to another.

$$DTED\ (ethylbenzene) = \frac{408 \times (5/7)}{100} = 2.91\ \text{mg/kg} - \text{bw/day}$$

A3.4 Xylenes

The oral DTED for xylenes applied in this project (11.9 mg/kg-bw/day), was derived based on the reported LOAEL from a study by the National Toxicology Program (1986). Rats were orally gavaged with doses ranging from 0 to 1,000 mg/kg for 103 weeks (5 days/week). The reported LOAEL, based on central nervous system toxicity, was 500 mg/kg-bw/day. When adjusted for a continuous exposure (*i.e.*, to 7 days/week from 5 days/week), the LOAEL becomes 357 mg/kg-bw/day. A 30-fold uncertainty factor was applied, based on a 3-fold uncertainty factor to account for uncertainties within the toxicological database, and a further 10-fold factor to account for uncertainties in extrapolating from one species to another.

$$DTED\ (xylenes) = \frac{500 \times (5/7)}{30} = 11.9\ \text{mg/kg} - \text{bw/day}$$

DRAFT

A4. FRESHWATER AQUATIC LIFE

Freshwater aquatic life water quality guidelines were required for this project, in order to derive soil quality guidelines protective of freshwater aquatic life. Water quality guidelines for freshwater aquatic life are available for benzene, toluene, and ethylbenzene (AENV, 1999; CCME, 1999). A freshwater aquatic life guideline has not been developed by these agencies for xylenes.

A significant amount of data are available concerning the freshwater aquatic toxicity of xylenes. These data, downloaded from the US EPA ECOTOX database (US EPA 2001), are summarized in Table A-3. Note that data for marine or estuarine species, and data for non-toxicological effects (e.g., avoidance) are not included. References are included in Table A-3, but are not reproduced in the

references in Section 5. A full review of the source papers of these data, including a check for compliance with the requirements of the CCME (1999) protocol for developing water quality guidelines for freshwater aquatic life, is outside the scope of this report.

The dataset was simplified and reduced as follows:

- multiple data points for the same species, endpoint, effect, and duration were combined by taking the geometric mean; and,
- where data points were available for the same species, endpoint, and effect, but different durations, only the longest duration data were considered.

The reduced data is presented in Table A-4.

A working value for a xylenes freshwater aquatic life guideline for the current project was developed based on the lowest concentration in the reduced dataset (3,643 µg/L, 48 hr *Daphnia magna* immobilization EC50, Table A-2). This value was used, together with an application factor of 0.05 (acute test for a non-persistent variable) to give a guideline value of 180 µg/L for use in the current work. This calculation was based on the CCME (1999) protocol. A non-persistent variable is defined by CCME (1999) as having a degradation half life less than 8 weeks. The degradation half life of xylenes in surface water is given by Howard *et al.*, 1991 as 1-4 weeks. It should be noted that the issue of getting meaningful aquatic toxicity data from volatile compounds would need further study before deriving a definitive xylenes guideline.

DRAFT

A5. REFERENCES

AENV (Alberta Environmental Protection), 1999. Surface Water Quality Guidelines for Use in Alberta. Environmental Sciences Division. November 1999.

Allen, W.R., W. L. Askew and K. Schreiber, 1961. Effect of insecticide fertilizer mixtures and seed treatment on emergence of sugar beet seedlings. *J. Econ. Entomol.* **54**:181-187.

Anderson, T.A., J.J. Beauchamp and B.T. Walton, 1991. Organic chemicals in the environment: fate of volatile and semivolatile organic chemicals in soils: abiotic versus biotic losses. *J. Environ. Qual.*, **20**, 420-424.

Bruns, V.F. and A.D. Kelly, 1974. Effect of Sprinkler Irrigation with Xylene-Treated Water on Six Crops. Bulletin 796. College of Agriculture Research Centre. Washington State University. Cited in CCME, 1999.

Callahan, C.A., M.A. Shirazi and E.F. Neuhauser, 1994. Co``mparative toxicity of chemicals to earthworms. *Environ. Toxicol. Chem.*, **13**, 291-298.

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg.

CCME (Canadian Council of Ministers of the Environment), 2000. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale, Supporting Technical Document. December, 2000.

Currier, H.B. and S.A. Peoples, 1954. Phytotoxicity of hydrocarbons. Hilgardia, 23, 155-173.

Currier, H.B., 1951. Herbicidal properties of benzene and certain methyl deriv[illegible]. *Hilgardia*, **20**, 383-406.

Efroymson, R.A., M.E. Will, G.W. Suter II and A.C. Wooten, 199[illegible] Toxicol[illegible]cal Benchmarks for Screening Contaminants for Potential Concern for Ef[illegible] on [illegible]trial [illegible]nts: 1997 Revisions. Prepared for the U.S. Department of Ener[illegible] Lockh[illegible] Mar[illegible] Energy [illegible]stems, Inc. Oak Ridge National Laboratory. ES/ER/TM-[illegible]/R[illegible]

Environment Canada, 1995. Toxic[illegible]g[illegible]ional [illegible]nit[illegible]ed Sites Remediation Program Priority Substances for the De[illegible]lop[illegible]nt [illegible] Q[illegible]ity Guidelines for Contaminated Sites. Environmental Conservation [illegible]vic[illegible] Ev[illegible]ati[illegible]nd Interpretation Branch, Guidelines Division. Ottawa, ON. Unpublished.

Environment Canada, 1998a. Deve[illegible]ment of Plant Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 75 (Appendices).

DRAFT

Environment Canada, 1998b. Development of Earthworm Toxicity Tests for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 52 (Appendices).

Environment Canada, 1998c. Development of a Reproduction Toxicity Test with *Onychiurus folsomi* for Assessment of Contaminated Soils. Prepared for Method Development and Application Division, Technology Development Directorate, Environment Canada, Ottawa, Ontario, pp. 250 (Appendices).

ESG International Inc., 2001. Toxicity Assessment of BTEX Compounds. Report prepared for Dr. Ted Nason, Alberta Environment, Environmental Science Division. June 2001.

Fuller, M.E. and K.M. Scow, 1996. Effects of toluene on microbially-mediated processes involved in the soil nitrogen cycle. *Microbial Ecology*, **32**, 171-184.

Fuller, M.E. and K.M. Scow, 1997. Impact of trichloroethylene and toluene on nitrogen cycling in soil. *Appl. Environ. Microbiol.*, **63**, 4015-4019.

Fuller, M.E., K.M. Scow, S. Lau and H. Ferris, 1997. Trichloroethylene (TCE) and toluene effects on the structure and function of the soil community. Soil Biol. Biochem., 29, 75-89.

Hansson, G.B., L. Klemedtsson, J. Stenstrom and L. Torstensson, 1991. Testing the influence of chemicals on soil autotrophic ammonium oxidation. Environ. Toxicol. Water Qual., 6, 351-360. Cited in Fuller and Scow, 1996.

Hartenstein, R., 1982. Effect of aromatic compounds, humic acids and lignins on growth of the earthworm Eisenia foetida. Soil Biol. Biochem., 14, 595-599.

Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M., and Michalenko, [illegible], 1991. Environmental Degradation Rates. Lewis Publishers Inc., Chelsea, [illegible] p.

Hsieh, G.C., R.P. Sharma and R.D.R. Parker, 1988. Subclinical effects of groundwater contaminants. I. alteration of humoral and cellular immunity by benzene in C[illegible] mice. Arch. Environ. Contam. Toxicol., 17, 799-805. cited in U.S. EPA, 1988.

Hulzebos, E.M., D.M.M. Adema, E.M. Dirven-van Breemen, P.G. Henzen, W.A. van Dis, H.A. Herbold, J.A. Hoekstra, R. B[illegible], A.M. [illegible], 1993. Phytotoxicity Studies with Lactuca sativa in Soil and Nutrient Solution. Environ. Toxicol. Chem. 12:1079-1094.

Ivens, G.W., 1952. The phytotoxicity of mineral oils and hydrocarbons. Ann. Appl. Biol., 39, 418-422.

Keener, W.K. and D.J. Arp, 1994. Transformations of aromatic compounds by Nitrosomonas europaea. Appl. Environ. Microbiol., 60, 1914-1920.

Kirchmann, H., H. Astrom and G. Jonsall, 1991. Organic pollutants in sewage sludge: 1. effects of toluene, naphthalene, 2-methylnaphthalene, 4-n-nonylphenol and di-2-ethylhexyl phthalate on soil biological processes and their decomposition in soil. Swedish J. Agric. Res., 21, 107-113.

Miller, T.A., R.H. Rosenblatt, J.C. Darce, J.G. Pearson, R.K. Kulkarni, J.L. Welch, D.R. Cogley and G. Woodard, 1976. Problem Definition on Potential Environmental Pollutants IV: Physical, Chemical, Toxicological and Biological Properties of Benzene, Toluene, Xylenes and p-

DRAFT

Chlorophenyl Methyl Sulfide, Sulfoxide and Sulfone. U.S. Army Medical Bioengineering Research and Development Laboratory. Fredrick, MD. AD/A-040 435. Cited in Environment Canada, 1984 and Environment Canada, 1993.

Mu, D.Y. and K.M. Scow, 1994. Effect of trichloroethylene (TCE) and toluene concentrations on TCE and toluene biodegradation and the population density of TCE and toluene degraders in soil. Appl. Environ. Microbiol., 60, 2661-2665.

National Toxicology Program, 1986. NTP Technical Report of the Toxicology and Carcinogenesis of Xylenes (mixed) (60.2% m-xylene, 13.6% p-xylene, 17.0% ethylbenzene and 9.1% o-xylene) (CAS No. 1330-20-7) in F344/N Rats and B6C3F1 Mice (gavage studies). U.S. DHHS, PHS, NIH, NTP, Research Triangle Park, NC. NTP TR 327, NIH Publ. No. 86-2583. cited in U.S. EPA, 2000.

National Toxicology Program, 1989. Toxicology and Carcinogenesis Studies of Toluene in F344/N Rats and B6C3F1 Mice. Technical Report Series No. 371. Research Triangle Park, NC. cited in U.S. EPA, 2000.

Neuhauser, E.F., R.C. Loehr, M.R. Malecki, D.L. Milligan and P.R. Durkin, 1985. The toxicity of selected organic chemicals to the earthworm Eisenia fetida. J. Environ. Qual., 14, 383-388.

Overcash, R.M., J.B. Weber and M.L. Miles, 1982. Behavior of Organic Priority Pollutants in the Terrestrial System: Di-n-Butyl Phthalate Ester, Toluene, and 2,4 Dinitrophenol. UNC-WRRI-82-171. Water Resources Research Institute. University of North Carolina. Cited in Efroymson *et al.*, 1997.

Reynolds, T., 1989. Comparative effects of heterocyclic compounds on inhibition of lettuce fruit germination. J. Exper. Bot., 40, 391-404.

Schubert, U., L. Wisanowsky and U. Kull, 1995. Determination of [illegible] of several volatile organic compounds by investigating the germination [illegible] bacco p[illegible]en. J. Plant Physiol., 145, 514-518.

Sloof, W. and P.J. Blokzijl (eds.), 1988. Inte[illegible] Toluen[illegible] RIVM Research for Man and Environment. Nation[illegible] Public [illegible] Environmental Protection. The Netherlands. Report No. 758[illegible] Canada, 1992.

US EPA (U.S. Environmental Prote[illegible]), [illegible] Toxicological Review of Benzene (Noncancer Effects) (CAS N[illegible]) In Support of Summary Information on the Integrated Risk Information System (IRIS) [illegible]aft. U.S. Environmental Protection Agency. Washington, DC.

US EPA (U.S. Environmental Protection Agency), 2000. Integrated Risk Information System (IRIS). on-line database. U.S. Environmental Protection Agency.

US EPA (U.S. Environmental Protection Agency), 2001. IRIS online database. http://www.epa.gov/iris/

Vonk, J.W., D.M.M. Adema and D. Barug, 1986. Comparison of the Effects of Several Chemicals on Microorganisms, Higher Plants and Earthworms. In: Assink, J.W. and W.J. van den Brink (eds.).

DRAFT

F2

Contaminated Soil. First International TNO Conference on Contaminated Soil 11-15 November, 1985, Utrecht, The Netherlands. Martinus Nijhoff Publishers. Dordrecht, The Netherlands.

Walton, B.T., T.A. Anderson, M.S. Hendricks and S.S. Talmage, 1989. Physicochemical properties as predictors of organic chemical effects on soil microbial respiration. Environ. Toxicol. Chem., 8, 53-63.

Wolf, M.A., V.K. Rowe, D.D. McCollister, R.L. Hollingsworth and F. Oyen, 1956. Toxicological studies of certain alkylated benzenes and benzene. Arch. Ind. Health, 14, 387-398. cited in U.S. EPA, 2000.

DRAFT

Table 1.1. Chemical-Specific Data – BTEX and BaP

Parameter			Benzene	Toluene	Ethylbenzene	Xylenes	B(a)P
Human Toxicity and Availability							
Tolerable Daily Intake	TDI	mg/kg-bw/day	NA	0.22[a]	0.1[b]	1.5[a]	NA
Reference Concentration	RfC	mg/m^3	NA	3.8[a]	1[b]	0.16[a]	NA
Risk Specific Dose	RsD	mg/kg-bw/day	0.00069[c]	NA	NA	NA	0.0000014[b]
Risk Specific Concentration	RsC	mg/m^3	0.003[a]	NA	NA	NA	0.00016[a]
Gut Absorption Factor	AF_G	unitless	1[j]	1[j]	1[j]	1[j]	1[j]
Dermal Absorption Factor	AF_D	unitless	0.08[k]	0.12[k]	0.2[k]	0.12[k]	0.2[k]
Human Background Exposure							
Estimated Daily Intake	EDI	mg/kg-bw/day	NA	0.0028[d]	0.0029[e]	0.0079[f]	NA
Background Indoor Air Concentration	C_a	mg/m^3	NA	[illegible]	0.0075[e]	0.00182[f]	NA
Background Soil Concentration	BSC	mg/kg	0[j]	[illegible]	0[j]	0[j]	0[j]
Soil Allocation Factor	SAF	unitless	0.5[g]	0.5[g]	0.5[g]	0.5[g]	0.6[h]
Livestock/Wildlife Toxicity							
Daily Threshold Effects Dose	DTED	mg/kg-bw/day	[illegible].08[i]	4.46[i]	2.91[i]	11.9[i]	NA
Soil-Specific Partitioning Parameters							
Water Organic Carbon Partition Coefficient	K_{OC}	[illegible]g	[illegible].2	234[l]	537[l]	586[l]	NA
Henry's Law Constant	H'	unitless	0.225	0.274	0.358	0.252	NA
Decay Half-Life	$t_{1/2}$	[illegible]	365[m]	105[m]	114[m]	183[m]	NA
Diffusion Coefficient in Air	D_a	cm^2/s	0.088[l]	0.087[l]	0.075[l]	0.078[l]	NA
Solubility	S	mg/L	1,780[l]	515[l]	152[l]	198[l]	0.0038[l]

DRAFT

Notes:
NA = not applicable;
B(a)P = benzo(a)pyrene;
a. Health Canada (1996b
b. US EPA (2001);
10^{-5}.
c. Based on the RsC. (RsD = RsC x 16.2 m^3/day / 70.7 kg);
d. Health Canada (1992);
e. ATSDR (1999);
f. Health Canada (1993);
g. Soil allocation factor for PHC F1 (CCME, 2000);
h. Soil allocation factor for PHC F3 (CCME, 2000);
i. See Appendix A for derivation of the DTED;
j. assumed;
k. CCME (2000);
l. TPHCWG (1997);
m. BCMELP (1996); and,
The RsD and RsC are based on an incremental cancer risk of 1 x

Table 1.2. Chemical-Specific Data – F1 and F2 Sub-Fractions

Parameter			F1			F2			
			Aliphatic		Aromatic	Aliphatic		Aromatic	
			$C_{>6}-C_8$	$C_{>8}-C_{10}$	$C_{>8}-C_{10}$	$C_{>10}-C_{12}$	$C_{>12}-C_{16}$	$C_{>10}-C_{12}$	$C_{>12}-C_{16}$
Fraction Composition [a]	F_c	unitless	0.55	0.36	0.09	0.36	0.44	0.09	0.11
Tolerable Daily Intake [a]	TDI	mg/kg-bw/d	5	0.1	0.04	0.1	0.1	0.04	0.04
Reference Concentration [a]	RfC	mg/m^3	18.4	1	0.2	1	1	0.2	0.2
Estimated Daily Intake [a]	EDI	mg/kg-bw/d	0.02334	0.0103	0.00938	0	0	0	0
Background indoor Air Concentration [a]	C_a	mg/m^3	0.09111	0.03881	0.03745	0	0	0	0
Aquatic Life Guideline [a]	WQG_{AL}	mg/L	0.0465	0.0076	0.140	[illegible]18	0.000074	0.096	0.0554
Organic Carbon Partition Coefficient [a]	K_{OC}	mL/g	3,980	31,600	[illegible]	[illegible],000	5,010,000	2,510	5,010
Henry's Law Constant [b]	H'	unitless	50	80	[illegible]	[illegible]20	520	0.14	0.053

Notes:

a. CCME (2000); and,

b. TPHCWG (1997).

DRAFT

Table 1.3. Chemical-Specific Data – PHC Fractions F1-F4

Parameter			F1	F2	F3	F4
Gut Absorption Factor	AF_G	unitless	1.0	1.0	1.0	1.0
Dermal Absorption Factor	AF_D	unitless	0.2	0.2	0.2	0.2
Background Soil Concentration	BSC	mg/kg	0	0	0	0
Soil Allocation Factor	SAF	unitless	0.5	0.5	0.6	0.8
Daily Threshold Effects Dose	DTED	mg/kg-bw/d	9.74	8.95	14.5	9.64
Decay Half-Life	$t_{1/2}$	days	712	1,750	NA	NA
Diffusion Coefficient in Air	D_a	cm^2/s	0.05	0.05	NA	NA

Notes:
all values from CCME (2000); and,
NA = not applicable.

DRAFT

Table 2.1. Alberta Tier 1 Hydrocarbon Guidelines for Fine Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	**260**	**900**	**800**	**5,600**
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [1]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) [1]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	**260**	**900**	**800**	5,600
	Soil Ingestion (Livestock)	33	1,800	1,200	5,800	F3	4,000	3,700	6,000	**4,000**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Residential	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	4.3	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	**260**	**900**	**800**	**5,600**
	Protection of Groundwater for Aquatic	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Commercial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	**660**	**1,500**	**2,500**	**6,600**
	Protection of Groundwater for Aquatic	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Industrial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	**660**	**1,500**	**2,500**	**6,600**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA

DRAFT

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes:

1. this pathway can be excluded within 15 m of an oilfield wellhead;
***bold** = lowest value for each chemical and land use;*
underlined = PHC guidelines adopted without change from CCME (2000);
** the potable groundwater, aquatic life, and groundwater for wildlife pathways may not apply at a given site: see text for details;*
BaP = benzo(a)pyrene;
all values are presented to two significant figures
RES = calculated value exceeds 30,000 mg/kg;
NA = not applicable;
TBD = to be determined;
F3 = ecological endpoints for B(a)P are included in the guideline for F3; and,
F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 2.2 Alberta Tier 1 Hydrocarbon Guidelines for Coarse Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
Agricultural	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	**4.3**	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [1]	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) [1]	**0.048**	120	54	**14**	NA	**30**	**150**	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
	Soil Ingestion (Livestock)	33	1,800	1,200	5,900	F3	4,000	3,700	6,000	4,000
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Livestock	2.2	2,200	360	6,000	F3	11,000	8,600	NA	NA
Residential	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	**4.3**	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade)	**0.048**	120	54	**14**	NA	**30**	**150**	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	130	450	400	2,800
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	230	NA	NA
Commercial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	**16**	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1,400	630	160	NA	**310**	1,700	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13	71	200	130	F3	330	760	1,700	3,300
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
Industrial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	**16**	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1,400	630	160	NA	**310**	1,700	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13	71	200	130	F3	330	760	1,700	3,300
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA

DRAFT

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

Notes:

1. *this pathway can be excluded within 15 m of an oilfield wellhead;*

***bold** = lowest value for each chemical and land use;*

underlined = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife pathways may not apply at a given site: see text for details;*

BaP = benzo(a)pyrene;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and,

F3 = ecological endpoints for B(a)P are included in the guideline for F3; and,

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 2.3. Alberta Hydrocarbon Guidelines for Fine Subsoil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area [1]	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	750	2,200	3,500	10,000
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural [1]	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [2]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) [2]	1.9	4,800	2,100	520	NA	990	5,500	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	750	2,200	3,500	10,000
	Soil Ingestion (Livestock)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Residential	Human Soil Ingestion			NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact			NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement)			2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)			2,100	520	NA	990	5,500	NA	NA
	Protection of Potable Groundwater *		0.86	0.19	25	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)		300	450	1,200	F3	750	2,200	3,500	10,000
	Protection of Groundwater for Aquatic Life *		RES	RES	RES	F3	TBD	TBD	NA	NA
Commercial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	1,000	3,000	5,000	10,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Industrial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	1,000	3,000	5,000	10,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA

DRAFT

uidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

otes: 1. subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. this pathway can be excluded within 15 m of an oilfield wellhead;

***bold** = lowest value for each chemical and land use;*

underlined = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife; pathways may not apply at a given site: see text for details;*

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and,

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

Table 2.4. Alberta Hydrocarbon Guidelines for Coarse Subsoil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area [1]	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	**350**	1,500	**2,500**	**10,000**
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
Agricultural [1]	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [2]	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) [2]	**0.054**	140	61	**15**	NA	**40**	**190**	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	**350**	1,500	**2,500**	**10,000**
	Soil Ingestion (Livestock)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Livestock	2.2	2,[illegible]	[illegible]	[illegible],000	F3	11,000	8,600	NA	NA
Residential	Human Soil Ingestion	[illegible]	[illegible]	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	[illegible]	[illegible]A	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	[illegible]	[illegible]	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grad	[illegible]	[illegible]	61	**15**	NA	**40**	**190**	NA	NA
	Protection of Potable Groundwater *	[illegible]	1.6	**0.36**	49	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	[illegible]	48	180	180	F3	350	1,500	**2,500**	**10,000**
	Protection of Groundwater for Aquatic [illegible] *	[illegible].6	**0.16**	79	59	F3	360	230	NA	NA
Commercial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	**340**	1,800	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	**3,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
Industrial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	**340**	1,800	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	**3,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA

DRAFT

uidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of Volume 3 in this series.

otes: 1. subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. this pathway can be excluded within 15 m of an oilfield wellhead;

***bold** = lowest value for each chemical and land use;*

<u>underlined</u> = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife; pathways may not apply at a given site: see text for details;*

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and,

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 5.1. Exposure Point Water Quality Guidelines

Criteria	*Benzene (mg/L)*	*Toluene (mg/L)*	*Ethylbenzene (mg/L)*	*Xylenes (mg/L)*	*F1 (mg/L)*	*F2 (mg/L)*
Human Drinking Water	0.005 [1]	0.024 [1]	0.0024 [1]	0.3 [1]	4.6 [2]	2.1 [2]
Freshwater Aquatic Life	0.370 [3]	0.002 [3]	0.090 [3]	0.180 [4]	0.017 [5]	0.00016 [5]
Livestock Watering (Cattle)	0.51 [6]	29 [6]	19 [6]	76 [6]	62 [7]	57 [7]
Wildlife Watering	1.2 [8]	69 [8]	45 [8]	180 [8]	150 [9]	140 [9]

Notes:

1. *Health Canada (1996);*
2. *derived for this project by combining TDIs for hydrocarbon sub-fractions (see text);*
3. *CCME (1999);*
4. *derived for this project (see Appendix I);*
5. *derived from combining values for TPHCWG (1996) sub-fractions in Scientific Rationale Document (CCME, 2000);*
6. *derived for this project using daily threshold effect dose and physiological characteristics for dairy cow (see text);*
7. *from CCME (2000);*
8. *derived for this project using daily threshold effect dose and physiological characteristics for deer (see text); and,*
9. *derived from dairy cow data in CCME (2000) and deer body weight and forage ingestion rate.*

DRAFT

Table 5.2. Groundwater Quality Guidelines

Criteria	*Benzene (mg/L)*	*Toluene (mg/L)*	*Ethylbenzene (mg/L)*	*Xylenes (mg/L)*	*B(a)P (mg/L)*	*F1 (mg/L)*	*F2 (mg/L)*
			All Soils				
Human Drinking Water	0.005	0.024	0.0024	0.3	0.00001	4.6	2.1
Livestock Watering	0.51	29	19	76	NA	62	57
			All Soils; Piezometers <10 m from Surface Water Body				
Freshwater Aquatic Life	0.370	0.002	0.090	0.180	NA	ND	ND
Wildlife Watering	1.2	69	45	180	NA	150	140
			Coarse Soils; Piezometers >10 m from Surface Water Body				
Freshwater Aquatic Life	0.53	0.021	4.8		NA	NG	NG
Wildlife Watering	1.8	NG	NG	NG	NA	NG	NG
			Fine Soils; Piezometers >10 m from Surface Water Body				
Freshwater Aquatic Life	NG	NG		NG	NA	NG	NG
Wildlife Watering	NG	NG	G	NG	NA	NG	NG

DRAFT

Notes:
NG = no guideline required for this pathway – limited by solubility from ver[illegible] surface water dilution at 10 m offset;
NA = not applicable;
ND = not determined, due to uncertainties with the critical body resid[illegible] met[illegible] o[illegible] aquatic toxicity; and,
see Volume 2 of this project for further explanation of values in this [illegible]e.

Table A-1. Combined IC50/LC50 Data – Alberta Till (Fine)

Species	*Root/Shoot*	*Parameter*	*IC50/EC50*			
			Benzene (mg/kg)	*Toluene (mg/kg)*	*Ethylbenzene (mg/kg)*	*Xylenes (mg/kg)*
Northern	Shoot	Length	41.0	957.9	2,495.0	3,498.6
Wheatgrass	Shoot	Wet Mass	42.8	466.9	642.9	1,680.4
	Shoot	Dry Mass	35.9	424.2	728.7	1,386.6
	Root	Length	80.0	506.0	1,135.9	1,768.8
	Root	Wet Mass	9.4	219.9	308.1	1,371.8
	Root	Dry Mass	19.1	[illegible]	582.0	998.2
Eisenia andrei	Worm	Mortality	5.5	65.4	29.4	42.3
25th Percentile of Plant and Invertebrate Data			[illegible]	***302***	***445***	***1,185***
50th Percentile of Plant Data Only			[illegible]	***446***	***686***	***1,533***

DRAFT

Table A-2. Combined IC50/LC50 Data - Artificial Soil (Coarse)

Species	*Root/Shoot*	*Parameter*	*IC50/EC50*			
			Benzene (mg/kg)	*Toluene (mg/kg)*	*Ethylbenzene (mg/kg)*	*Xylenes (mg/kg)*
Northern	Shoot	Length	35.0	517.6	1,047.4	564.3
Wheatgrass	Shoot	Wet Mass	15.3	74.5	166.7	124.1
	Shoot	Dry Mass	7.7	68.5	212.2	134.5
	Root	Length	18.5	119.4	643.7	290.7
	Root	Wet Mass	10.1	19.3	15.5	65.4
	Root	Dry Mass	5.3	2	177.1	113.8
Eisenia andrei	Worm	Mortality	N/A	5.1	10.7	8.8
25th Percentile of Plant and Invertebrate Data			***.3***	***24***	***91***	***90***
50th Percentile of Plant Data Only				***71***	***195***	***129***

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Daphnia magna	Water flea	EC50	ITX	24	H	S	1,000	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	1,390	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The C[illegible]e Toxicity of Crude [illegible]d Oils to Daphnia magna an[illegible]rtemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	EC50	ITX	48	H	S	1,390	µg/L	MACLEAN, M.M. AND DOE	198[illegible]	Com[illegible]ative Toxicity of Crude and Ref[illegible]d Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	EC50	ITX	48	H	S	1,870	µ[illegible]	M[illegible]. AN[illegible] DO[illegible]	198[illegible]	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Oncorhynchus mykiss	Rainbow trout, Donaldson trout	LC50	MOR	96	H	R	2,600	µ[illegible]	[illegible]ASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	3,186	µg/L	BOBRA, A.M., W.Y. SHIU, AND D. MACKAY	1983	A Predictive Correlation for the Acute Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (Daphnia magna)	Chemosphere 12(9-10):1121-1129

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Selenastrum capricornutum	Green algae	EC50	GRO	72	H	S	3,200	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	3,530	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The [illegible]ve Toxicity of Crude [illegible]ed Oils to Daphnia magna a[illegible] Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	EC50	ITX	24	H	S	3,600	µg/L	GALASSI, S., [illegible]M. MING[illegible] V[illegible], C[illegible]ARE[illegible] A[illegible], [illegible]SA	19[illegible]	[illegible]proac[illegible]s to Modeling Toxic Respon[illegible] of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	F	3,820	[illegible]L	[illegible]LO[illegible]B[illegible]G[illegible], G.L. [illegible]P[illegible] A.[illegible]SULAIMAN, [illegible]ND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
Selenastrum capricornutum	Green algae	EC50	GRO	8	D	S	3,900	µg/L	HERMAN, D.C., W.E. INNISS, AND C.I. MAYFIELD	1990	Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga Selenastrum capricornutum	Aquat Toxicol 18(2):87-100

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Selenastrum capricornutum	Green algae	EC50	GRO	8	D	S	4,200	µg/L	HERMAN, D.C., W.E. INNISS, AND C.I. MAYFIELD	1990	Impact of Volatile Aromatic Hydrocarbons, Alone and in Combination, on Growth of the Freshwater Alga Selenastrum capri	Aquat Toxicol 18(2):87-100
Selenastrum capricornutum	Green algae	EC50	GRO	8	D	S	4,400	µg/L	HERMAN, D.C., W.E. INNISS, AND C.I. MAYFIELD	19	f Volatile Aromatic Hydroca ns, Alone and in mbina n, on Growth of the Freshwa Alga Selenastrum capricornutum	Aquat Toxicol 18(2):87-100
Selenastrum capricornutum	Green algae	EC50	GRO	72	H	S	4,700		A S. GI VIGANO, C AND M.L. SATO	19	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	24	H	S	4,700		GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	4,730	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Selenastrum capricornutum	Green algae	EC50	GRO	72	H	S	4,900	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	5,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The [illegible]ive Toxicity of Crude [illegible]ed Oils to Daphnia magna [illegible] Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	EC50	ITX	48	H	S	5,030	µg/L	MACLEAN, M.M. AN[illegible]G. 19[illegible] DOE		[illegible] Co[illegible]arative Toxicity of Crude and R[illegible]ed Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	48	H	S	5,770	[illegible]	[illegible]CL[illegible]M. [illegible] [illegible]E	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	48	H	S	7,090	[illegible]	[illegible]ACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Oncorhynchus mykiss	Rainbow trout, Donaldso n trout	LC50	MOR	96	H	R	7,600	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Oncorhynchus mykiss	Rainbow trout, Donaldson trout	LC50	MOR	96	H	F	8,050	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
Oncorhynchus mykiss	Rainbow trout, Donaldson trout	LC50	MOR	96	H	R	8,400	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AN[illegible] TOSA[illegible]	19[illegible]	[illegible]s to Modeling Toxic Respons[illegible] of Aquatic Organisms Aroma[illegible] Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Daphnia magna	Water flea	EC50	ITX	48	H	S	8,496	µg/L	[illegible]OBR[illegible] A.[illegible] W.[illegible] SH[illegible] [illegible] AY	19[illegible]	A Predictive Correlation for the Acute Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (Daphnia magna)	Chemosphere 12(9-10):1121-1129
Artemia	Brine shrimp	LC50	MOR	48	H	S	8,520	µg/L	[illegible]ACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	48	H	S	8,540	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Poecilia reticulata	Guppy	LC50	MOR	96	H	R	8,800	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Artemia	Brine shrimp	LC50	MOR	48	H	S	8,840	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The [illegible]ive Toxicity of Crude [illegible]ed Oils to Daphnia magna a[illegible] Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	EC50	ITX	48	H	S	9,558	µg/L	BOBRA, A.M., W.Y. [illegible]U, 19[illegible] AND [illegible]Y	[illegible]	Pred[illegible]ve Correlation for the Acute T[illegible]city of Hydrocarbons and Chlorinated Hydrocarbons to the Water Flea (Daphnia magna)	Chemosphere 12(9-10):1121-1129
Artemia	Brine shrimp	EC50	ITX	48	H	S	10,700	[illegible]L	[illegible]CL[illegible]N, [illegible]M. [illegible]D K.G. [illegible]E	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	48	H	S	10,900	[illegible]	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Poecilia reticulata	Guppy	LC50	MOR	96	H	R	12,000	µg/L	GALASSI, S., M. MINGAZZINI, L. VIGANO, D. CESAREO, AND M.L. TOSATO	1988	Approaches to Modeling Toxic Responses of Aquatic Organisms to Aromatic Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Artemia	Brine shrimp	LC50	MOR	48	H	S	12,200	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	48	H	S	12,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Poecilia reticulata	Guppy	LC50	MOR	96	H	R	12,900	µg/L	GALASSI, S., M. MINGAZZINI, L. V D, D. C AN SA	19	Approac to Modeling Toxic spon of Aquatic Organisms to Arom Hydrocarbons	Ecotoxicol Environ Saf 16(2):158-169
Carassius auratus	Goldfish	LC50	MOR	24	H	S	13,000	µg/L	D L., NTER	19	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626
Artemia	Brine shrimp	LC50	MOR	48	H	S	14,800	µg/L	CL N, M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	LC50	MOR	48	H	S	15,700	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Carassius auratus	Goldfish	LC50	MOR	24	H	S	16,000	µg/L	BRIDIE, A.L., C.J.M. WOLFF, AND M. WINTER	1979	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Pimephales promelas	Fathead minnow	LC50	MOR	96	H	F	16,000	µg/L	GEIGER, D.L., L.T. BROOKE, AND D.J. CALL	1990	Acute Toxicities of Organic Chemicals to Fathead Minnows (Pimephales promelas), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, W I:332
Carassius auratus	Goldfish	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
Catostomus commersoni	White sucker	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
Lepomis macrochirus	Bluegill	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Pimephales promelas	Fathead minnow	LC50	MOR	96	H	F	16,100	µg/L	HOLCOMBE, G.W., G.L. PHIPPS, A.H. SULAIMAN, AND A.D. HOFFMAN	1987	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invert[illegible] Families	Arch Environ Contam Toxicol 16:697-710
Pimephales promelas	Fathead minnow	LC50	MOR	96	H	F	16,400	µg/L	GEIGER, D.L., L.T. BROOKE, AND D.J. C[illegible]L	19[illegible]	[illegible]xicities of Organic Chemicals to Fathead Minnows ([illegible]mephales promelas), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, W I:332
Pimephales promelas	Fathead minnow	LC50	MOR	96	H	F	16,400	µg/L	GEIG[illegible].L., [illegible]ROO[illegible]E, A[illegible]D. [illegible]CA[illegible]	19[illegible]	Acute [illegible]xicities of Organic Chemicals to Fathead Minnows (Pimephales promelas), Vol. 5	Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, W I:332
Artemia	Brine shrimp	EC50	ITX	24	H	S	16,500	[illegible]L	[illegible]CL[illegible]N, [illegible]M. [illegible]D K.G. [illegible]E	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	LC50	MOR	48	H	S	17,200	[illegible]	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Carassius auratus	Goldfish	LC50	MOR	24	H	S	18,000	µg/L	BRIDIE, A.L., C.J.M. WOLFF, AND M. WINTER	1979	The Acute Toxicity of Some Petrochemicals to Goldfish	Water Res 13(7):623-626

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Daphnia magna	Water flea	LC50	MOR	48	H	S	19,600	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Artemia	Brine shrimp	EC50	ITX	24	H	S	20,600	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Aplexa hypnorum	Snail	LC50	MOR	96	H	F	22,400	µg/L	HOLCOMBE, G.W. [illegible] PHIPPS, A.H. SUL[illegible] AND A[illegible]	[illegible]	Simultaneous Multiple Species Testing: Acute Toxicity of 13 Chemicals to 12 Diverse Freshwater Amphibian, Fish, and Invertebrate Families	Arch Environ Contam Toxicol 16:697-710
Daphnia magna	Water flea	LC50	MOR	48	H	S	23,600	µg/L	[illegible]	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	LC50	MOR	48	H	S	28,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	LC50	MOR	48	H	S	31,500	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64

DRAFT

Table A-3. Freshwater Aquatic Toxicity Data for Xylenes (Continued)

Scientific Name	Common Name	Endpoint	Effect	Test Duration	Duration Units	Exposure Type	Concentration	Concentration Units	Author	Year	Title	Reference Source
Daphnia magna	Water flea	LC50	MOR	48	H	S	33,100	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Daphnia magna	Water flea	LC50	MOR	48	H	S	37,000	µg/L	MACLEAN, M.M. AND K.G. DOE	1989	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Chlorella vulgaris	Green algae	EC50	GRO	24	H	S	55,000	µg/L	KAUSS, P.B. AND C. HUTCHINSON	19	The Effects of Water-Soluble Petroleum Components on the Growth of Chlorella vulgaris Beijerinck	Environ Pollut 9(3):157-174
Daphnia magna	Water flea	LC50	MOR	48	H	S	55,700		MACLEAN, M.M. AND K.G. DOE	19	The Comparative Toxicity of Crude and Refined Oils to Daphnia magna and Artemia	Environment Canada, EE-111, Dartmouth, Nova Scoti a:64
Xenopus laevis	Clawed toad	LC50	MOR	48	H	S	73,000		DE ZWART, D. AND W. SLOOFF	1987	Toxicity of Mixtures of Heavy Metals and Petrochemicals to Xenopus laevis	Bull Environ Contam Toxicol 38(2):345-351
Tetrahymena pyriformis	Ciliate	IC50	POP	2	D	NR	88,100	µg/L	SCHULTZ, T.W., S.E. BRYANT, AND T.S. KISSEL	1996	Toxicological Assessment in Tetrahymena of Intermediates in Aerobic Microbial Transformation of Toluene and p-Xylene	Bull Environ Contam Toxicol 56(1):129-134

DRAFT

NOTES:
Effect: GRO = growth; ITX = immobilization; MOR = mortality; POP = population growth.
Exposure Type: F = flow-through; R = renewal; S = static.

Table A-4. Reduced Freshwater Aquatic Toxicity Dataset for Xylenes

Species	*Endpoint*	*Effect*[1]	*Duration* (hours)	*Number of Data Points*[2]	*Concentration*[2] (µg/L)
Daphnia magna	EC50	ITX	48	11	3,643
Selenastrum capricornutum	EC50	GRO	192	3	4,162
Oncorhynchus mykiss	LC50	MOR	96	4	6,046
Poecilia reticulata	LC50	MOR	96	3	11,085
Carassius auratus	LC50	MOR	96	1	16,100
Catostomus commersoni	LC50	MOR	96	1	16,100
Lepomis macrochirus	LC50	MOR	96	1	16,100
Pimephales promelas	LC50	MOR	96	4	16,224
Aplexa hypnorum	LC50	MOR	96	1	22,400
Daphnia magna	LC50	MOR	48	9	26,956
Chlorella vulgaris	EC50	GRO	4	1	55,000
Xenopus laevis	LC50	MO	8	1	73,000
Tetrahymena pyriformis	IC50	PO		1	88,100

DRAFT

Notes:

10. Effect: GRO = growth; ITX = immobilization; MOR = mortality; P = ul n g and,

11. Where more than one data point is available, the concentratio ese d i e geometric mean.

ALBERTA SOIL AND WATER QUALITY GUIDELINES FOR HYDROCARBONS AT UPSTREAM OIL AND GAS FACILITIES

VOLUME 3: USER GUIDE

September 2001

DRAFT

LEGISLATURE LIBRARY
DEC - 4 2001
EDMONTON

Alberta Environment

Pub. No: T/622
ISBN: 0-7785-1897-3 Printed Edition
ISBN: 0-7785-1900-7 On-line Edition
Web Site: http://www.gov.ab.ca/env/

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Land Branch
Science and Standards Division
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-5883
Fax: (780) 422-4192

or by e-mail to : Ted.Nas[illegible]@g[illegible].a[illegible]a

DRAFT

Additional copies of this documen[illegible]be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

September 2001

TABLE OF CONTENTS

1. INTRODUCTION 1
   1.1 Background 1
   1.2 Regulatory Context 1
   1.3 Case Studies 3

2. GUIDELINE DECISION PROCESS 3
   2.1 Decision on Closure Type 3
      2.1.1 Type A - Unconditional Closure 3
      2.1.2 Type B - Unconditional Closure (On-Site Management) 4
      2.1.3 Type C - Conditional Closure 4
   2.2 Decision on Guideline Tier 4
      2.2.1 Tier 1 (Generic) Guidelines 5
      2.2.2 Tier 2 (Modified Generic) Guidelines 5
      2.2.3 Tier 3 (Site-Specific Risk Assessment) 5
   2.3 Determination of Management Level 5
   2.4 Determination of Soil Type 6
   2.5 Determination of Land Use 6
   2.6 Selection of Applicable Exposure Pathways 7
   2.7 Selection of Chemicals of Concern 8
      2.7.1 Determining When PAH Analysis is Required 8
      2.7.2 Expressing PAH Results as Benzo(a)pyrene Equivalent Concentration 10
   2.8 Subsoil Guidelines 10

3. SITE ASSESSMENT 10
   3.1 Sampling 10
   3.2 Analytical Requirements 11

4. USING TIER 1 GUIDELINES 11
   4.1 Soil 12
      4.1.1 Applicability of Tier 1 Guidelines 12
      4.1.2 Tier 1 Decision Tree 12
      4.1.3 Subsoil Guidelines 13
   4.2 Groundwater 13
   4.3 Regulatory Acceptance 14

5. USING TIER 2 GUIDELINES 14
   5.1 Tier 2A 15
      5.1.1 Introduction 15
      5.1.2 Tier 2A Adjustments 16
         5.1.2.1 Human Indoor Vapour Inhalation 16
         5.1.2.2 Protection of Potable Groundwater 17

DRAFT

5.1.2.3 Protection of Groundwater for Aquatic Life or Livestock Watering 18
5.1.2.4 Adjusting Hydrocarbon Composition.....19
5.1.3 Tier 2A Groundwater Guidelines.....19
5.1.4 Regulatory Acceptance.....19
5.2 Tier 2B.....19
5.2.1 Subsoil Guidelines 20
5.2.2 Ecological Soil Contact Pathway Suspended at Paved or Gravelled Sites.....20
5.3 Tier 2C.....20
5.3.1 Requirements 21
5.3.2 Regulatory Acceptance.....22
6. SITE-SPECIFIC (TIER 3) REMEDIATION OBJECTIVES 22
7. REFERENCES.....24

LIST OF TABLES

Table 1 Management Levels
Table 2 Relative Carcinogenic Potency Factors fo AH mpounds
Table 3 Alberta Tier 1 Hydrocarbon Guid lines f ne S Soil
Table 4 Alberta Tier 1 Hydrocarbon nes ars urface S
Table 5 Alberta Hydrocarb ide es Fin oil
Table 6 Alberta Hydrocar Guide r C on
Table 7 Alberta Hydrocar n G le es G undwater

DRAFT

LIST OF FIGURES

Figure 1 Regulatory Process for Tier 1, Tier 2, and Tier 3 Guidelines
Figure 2 Decision Tree for Tier 1 Soil Guideline Selection

LIST OF CASE STUDIES (IN PREPARATION)

Case Study 1 Flare Pit
Case Study 2 Pipeline Break

1. INTRODUCTION

1.1 Background

The operation of upstream oil and gas facilities can result in the release of hydrocarbon compounds to the environment. This can be a concern either during the operation of the facility, or after decommissioning when land is returned to its former use. Site closure is a term often used to describe regulatory acceptance that decommissioning is complete, and the land is ready to revert to its former or a new use. The hydrocarbon soil and groundwater quality guidelines presented here were developed to assist in environmental management and site closure of upstream oil and gas facilities in Alberta.

This document is the final part of a three volume report on hydrocarbon soil and groundwater quality guidelines for the upstream oil and gas industry in Alberta. Volume 1 provided the protocol for guideline development. Volume 2 described in detail the guideline development process. This document (Volume 3) summarizes the guideline values and provides guidance on how the guidelines are to be used.

DRAFT

It should be noted that, in addition to hydrocarbons, there are a range of other chemicals that could be released from upstream oil and gas facilities, including salts, metals, and process chemicals. If these other chemicals are present at a site, they will require assessment and/or management. See *Salt Contamination Assessment and Remediation Guidelines* (AENV 2001a) and CCME (1999) for information on compounds not directly addressed in this guidance document.

1.2 Regulatory Context

Current Alberta Environment policy ("*A Proposed Management Framework for Reclamation and Remediation of Oil and Gas Exploration and Production Sites in Alberta*; AENV 2000a) defines and differentiates two groups of activities related to site closure:

- *Reclamation* refers to activities that restore the *surface* of the land to it's former capability (grade, ability to support crops, etc.).
- *Remediation* refers to activities that address issues of contaminant concentrations in soil, subsoil and groundwater at a site.

Successful reclamation is acknowledged by a reclamation certificate. Procedures for obtaining a reclamation certificate are documented elsewhere (*e.g.*, AENV, 1995) and are not repeated here. Closure conditions that are compatible with the issue of a reclamation certificate are highlighted in Table 1.

Successful remediation activity is currently acknowledged by AENV through the issue of letters of compliance only within municipal zoning systems. Letters of compliance are **not** presently issued against

remedial activities at upstream oil and gas sites. However, three states of closure are defined here based on AENV (2000a): A) Unconditional Closure B) Unconditional Closure with acknowledgement that passive on-site management is included in the closure conditions for the site, and C) Conditional Closure, requiring off-site conditions to be addressed. These 3 closure states correspond to 3 different closure documents (Table 1). A fourth type of closure, "Deferred Closure" is defined in AENV (2000a), but is not discussed further in this document. One of the main functions of the guidelines developed by this project is to set standards for issuing letters of compliance.

Another recent regulatory document (AENV, 2000b) sets out current guidance for risk management at contaminated sites. Three options for risk management are provided (Figure 1), corresponding to the three Tiers of guidelines discussed in this document. Tier 1, or generic guidelines are numerical values that are protective of human and ecological health at a wide variety of sites throughout Alberta. Tier 2 is defined in AENV (2000b) as a modification of Tier 1 guidelines that may be developed by a proponent by replacing generic with site specific parameters in guideline calculations for certain pathways. Tier 3 refers to site-specific risk assessment and/or risk management.

DRAFT

Combining closure conditions and levels of risk management level. Seven management levels are defined, of which four are presently applicable to upstream oil and gas sites. In the list below, entries that are greyed out are **not** presently applicable for management of upstream oil and gas sites:

Tier 1
Tier 2A
Tier 2B
Tier 2C
Tier 3A
Tier 3B
Tier 3C

Management to Tier 1 or Tier 2A (which are effectively equivalent) is the most desirable outcome. Occasionally, situations will arise where site-specific risk assessment/risk management is appropriate and/or necessary. Tier 3A entails site-specific assessment of all pathways considered at Tier 1 and management to the same environmental endpoints. Most often this will be based on adoption of Tier 1 human health guidelines and development of site-specific eco-contact objectives from a battery of bioassays. Tier 3C is on-going management of difficult sites based on site-specific assessment. Such sites are not eligible for the reclamation certification process. Tiers 2B, 2C, and 3B are not presently applicable to upstream oil and gas sites in Alberta.

Providing guidance on site-specific risk assessment is outside the scope of this document. This Volume includes sufficient information for users of Tier 1 guidelines. Proponents wishing to develop Tier 2 and Tier 3 guidelines will find useful information in all three volumes. Assistance with determining the appropriate guideline Tier to use is provided in Section 2.2.

Further discussion of closure conditions, tiers and management levels is provided in Section 2. Concepts introduced there are illustrated in Appendices 1 and 2.

1.3 Case Studies

Two Case Studies are provided in Appendices 1 and 2 to illustrate the processes described in this User Guide. Case Study 1 considers a flare pit at a wellsite, while Case Study 2 is based on a pipeline break.

2. GUIDELINE DECISION PROCESS

There are a number of decisions required in order to select and develop the appropriate set of guidelines for a particular site. Each of the following Sections highlights one of these decisions, and explains how that decision is made.

DRAFT

2.1 Decision on Closure Type

Three potential closure conditions for Upstream Oil and Gas Sites in Alberta are considered in this document. Type A closure is the desired outcome and the only type eligible for a reclamation certificate at present. Types B and C are presented as technical options for discussion. Management level 3C is accessible for on-going management of sites not eligible for a reclamation certificate

- Type A - Unconditional Closure;
- Type B - Unconditional Closure (On-Site Management); and,
- Type C - Conditional Closure.

All three closure conditions aim to provide the same level of protection to human health and the environment. Differences arise mainly in how, by whom, and over what period risks are managed (AENV, 2000a). The three closure conditions are described in more detail in the following Sections.

2.1.1 Type A - Unconditional Closure

Type A Closure implies that all normal activities that could occur under the land use designation are protected, (*i.e.*, land use is not restricted). Sites may be eligible for Unconditional Closure either i) by being "screened out" from further consideration after a rigorous Phase 1 assessment; ii) after analytical testing that shows compliance with the Unconditional Closure guidelines for soil and groundwater; or, iii) after remediation and confirmatory analyses that show compliance with the Unconditional Closure guidelines for soil and groundwater (AENV, 2000a). Unconditional Closure is the preferred option at any site where it is technically and economically feasible.

NB. Greyed out entries throughout the text are not presently available for management of upstream oil and gas sites.

2.1.2 Type B - Unconditional Closure (On-Site Management)

Type B closure could be used to acknowledge certain conditions at sites where on-site contamination exceeds Type A closure guidelines, but where exposure to human and ecological receptors does not exceed acceptable limits *under present conditions*. The purpose of Type B closure is to maintain a record of contaminant conditions at a site that might become important if plans for that site change (within the same land use) in the future.

2.1.3 Type C - Conditional Closure

DRAFT

Type C Closure is an option that may be available when technical or economic considerations make Types A or B Closure impractical. This option presently applies at Tier 3 only. Type C Closure is used where off-site contamination is present and institutional or engineered controls are required to restrict human or ecological exposure through one or more pathways. Type C Closure therefore allows certain guidelines to be relaxed while maintaining the same level of human and ecological protection as with Types A and B Closure. Landowner participation is a crucial element of a risk management plan involving Type C Closure. Sites managed to Type C closure at Tier 3 are not eligible for a Reclamation Certificate.

2.2 Decision on Guideline Tier

Current AENV policy on risk management at contaminated sites is provided in the document:

- *Policy for Management of Risks at Contaminated Sites in Alberta.* AENV (2000b).

Proponents should familiarize themselves with the framework laid out in this document. Three Options are provided in AENV (2000b). These three Options correspond to the three guideline Tiers used in this project. Figure 1 summarizes how the three Tiers of guidelines fit into the regulatory process from site assessment to regulatory acceptance. The three Tiers are as follows:

- Tier 1 or generic guidelines;
- Tier 2 or modified generic guidelines; and,
- Tier 3 or risk based site-specific remediation objectives.

The following three Sections provide more detail about the three Tiers, and guidance as to when each Tier is applicable.

NB. Greyed out entries throughout the text are not presently available for management of upstream oil and gas sites.

2.1.2 Type B - Unconditional Closure (On-Site Management)

Type B closure could be used to acknowledge certain conditions at sites where on-site contamination exceeds Type A closure guidelines, but where exposure to human and ecological receptors does not exceed acceptable limits *under present conditions*. The purpose of Type B closure is to maintain a record of contaminant conditions at a site that might become important if plans for that site change (within the same land use) in the future.

2.1.3 Type C - Conditional Closure

Type C Closure is an option that may be availab[illegible]hen [illegible]cal o[illegible]conomic considerations make Types A or B Closure impractical. Th[illegible] pr[illegible]y a[illegible]es at Tie[illegible] only. Type C Closure is used where off-site contamination i[illegible]ese[illegible]and [illegible]nsti[illegible]io[illegible] o[illegible]ngineered controls are required to restrict human or ecological expos[illegible]g[illegible]r m[illegible]. Type C Closure therefore allows certain guidelines to be relaxed w[illegible] m[illegible]ta[illegible]ng[illegible]e [illegible]me level of human and ecological protection as with Types A and B Closure. [illegible]and [illegible]n[illegible]pa[illegible]pation is a crucial element of a risk management plan involving Type C Closure. [illegible]an[illegible]ed to Type C closure at Tier 3 are not eligible for a Reclamation Certificate.

DRAFT

2.2 Decision on Guideline Tier

Current AENV policy on risk management at contaminated sites is provided in the document:

- *Policy for Management of Risks at Contaminated Sites in Alberta.* AENV (2000b).

Proponents should familiarize themselves with the framework laid out in this document. Three Options are provided in AENV (2000b). These three Options correspond to the three guideline Tiers used in this project. Figure 1 summarizes how the three Tiers of guidelines fit into the regulatory process from site assessment to regulatory acceptance. The three Tiers are as follows:

- Tier 1 or generic guidelines;
- Tier 2 or modified generic guidelines; and,
- Tier 3 or risk based site-specific remediation objectives.

The following three Sections provide more detail about the three Tiers, and guidance as to when each Tier is applicable.

2.2.1 Tier 1 (Generic) Guidelines

Generic guidelines are based on identification of the values (i.e., receptors) to be protected under each land use, the applicable exposure pathways and a corresponding set of parameters which allow reasonably conservative predictions of risk at sites throughout Alberta. Tier 1 guidelines are expected to be applicable to the majority of upstream oilfield sites in Alberta. There will, however, be a few sites where site conditions result in a *more* sensitive scenario than the conservative generic scenarios considered (*e.g.*, a site underlain by very coarse sand and gravels with a high hydraulic conductivity, see Section 4.1.1). In such cases, a Tier 2 or Tier 3 approach will be required. Even at sites that eventually use a Tier 2 or Tier 3 approach, Tier 1 guidelines are normally used for an initial screening as the first step in a phased site assessment. The use of Tier 1 guidelines is described in detail in Section 4.

2.2.2 Tier 2 (Modified Generic) Guidelines

There may be circumstances where, based on the conditions at a particular site, the generic guidelines are unnecessarily conservative. Accordingly, guidance is provided in Section 5 on ways in which the generic guidelines can be changed and, in particular, including a discussion of parameters that could have their generic values replaced by site-specific values. In general, a decision to proceed with a Tier 2 approach will be made by weighing the additional effort of collecting further site data and developing Tier 2 guidelines against potential savings in remedial effort.

DRAFT

2.2.3 Tier 3 (Site-Specific Risk Assessment)

Large or complex sites may require site-specific risk assessment, with or without toxicity testing, to develop appropriate remediation objectives. Regulatory guidance is available to assist with this process, and some information in all three Volumes of this project may be of use, but such work is outside the scope of the present document.

2.3 Determination of Management Level

The combination of closure type and guideline Tier is referred to as the "Management Level". Tiers 2 and 3 are subdivided into 3 Management Levels each, corresponding to the three closure types (A, B, and C). Tier 1 is not subdivided. As stated in Sections 1.2 and 2.1, only management level A is presently eligible for a Reclamation Certificate. The available Management Levels are summarized in Table 1.

2.4 Determination of Soil Type

Generic guidelines are available for two soil types, Coarse and Fine. These soils are defined as having a median grain size greater or less than 75 microns, respectively.

Selection of the appropriate set of guidelines is based on the soil type that controls contaminant migration at the site, based on professional judgement. For example, a continuous layer of Coarse soil beneath the water table will often govern groundwater flow in the saturated zone, even though its thickness may be small in relation to the total thickness of saturated Fine soils. In cases where it is not clear which soil type should be applied at a site, the more conservative guidelines for Coarse soil will be applied.

2.5 Determination of Land Use

Soil guidelines have been developed for five ener l us – natural area, agriculture, residential/parkland, commercial and in al. ner and use enario is envisioned for each category based on the "normal" acti s the ds. or most ites in Alberta, one of the five generic land use scenarios s e a li le. of e generic land uses are applicable, a Tier 3 approach will be required. e fi la an efin as follows:

DRAFT

Natural Areas: are define as ing way from human habitation and activities, where the primary concern is the protection of gical receptors. Accordingly, human soil ingestion, dermal contact and indoor air inhalation are not considered, as these pathways are not expected to be limiting in this land use. However, the protection of groundwater for drinking water pathway *is* included in this land use, based on the AENV definition (AENV, 2001b) of a domestic use aquifer (DUA), which applies in all land uses. Much of the "green area" (*i.e.*, the boreal forest) of Alberta, and wildlands in national or provincial parks will fall into natural area land use. *Lands within the Green Area that are specified as grazing leases represent an intergrade to Agricultural land use. On such grazing leases, the Soil Ingestion (Livestock) and Protection of Groundwater for Livestock pathways MUST be addressed.*

Agricultural Lands: the primary land use is growing crops or tending livestock. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. The portion of a farm that houses people is considered a residential land use. Based on an interpretation of guidance from the Alberta Energy and Utilities Board (EUB, 1996 and 1999), it is assumed that a setback of at least 15 m is present between an oilfield wellhead and any present or future residence.

Residential Land Use: is where the primary activity is residential or recreational activity. This land use includes urban parks, and campground areas, but not wildlands in national or provincial parks.

Commercial Land Use: the primary activity is commercial (*e.g.*, shopping mall) and there is free access to all members of the public, including children. The use may include, for example, commercial day-care centers. It does not include operations where food is grown. Commercial land use is not anticipated to be a frequent future use of upstream oil and gas facilities, but is included to retain completeness and compatibility with other documents, including CCME (2000a,b).

Industrial Land Use: the primary activity involves the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

2.6 Selection of Applicable Exposure Pathways

There are a wide range of exposure pathways by which chemicals [illegible]ern may reach human and ecological receptors. The pathways considered by this pro[illegible]ted from CCME (2000a) and are summarized below:

DRAFT

Human pathways

- soil ingestion;
- soil dermal contact;
- *indoor vapour inhalati[illegible] ar
- *protection of potable [illegible]

Ecological Pathways

- plant/invertebrate soil contact;
- soil ingestion by livestock or wildlife;
- *protection of groundwater for aquatic life;
- protection of groundwater for livestock watering; and,
- *protection of groundwater for wildlife watering.

The pathways without an asterisk (*i.e.* the direct contact pathways plus indoor vapour inhalation and livestock watering) are always included (if applicable to the land use scenario) for Unconditional Closure. The groundwater pathways marked with an asterisk may be excluded in the following circumstances:

- The indoor vapour inhalation pathway can be excluded for areas within 15 m of an oilfield wellhead. This is based on the EUB guidance for construction setbacks from current or former wellheads.
- The human ingestion of groundwater pathway may be excluded if either i) the site is not underlain by a domestic use aquifer as defined by current AENV policy (AENV, 2001b), or ii) the contaminated material is not hydraulically connected to any underlying DUA. A 5 m thickness of massive, unfractured saturated Fine-grained material, with a bulk hydraulic conductivity less than 10^{-7} m/s is considered sufficient to ensure isolation between groundwater units). **Contamination of a DUA**

beyond Canadian Drinking Water Guidelines triggers remedial activity. Sites where contamination has compromised a DUA are not eligible for a Reclamation Certificate. Proponents wishing to exclude the human ingestion of groundwater pathway should familiarize themselves with the definition of a DUA laid out in AENV (2001b). As a guide, water-bearing units with a horizontal hydraulic conductivity less than 10^{-6} m/s are unlikely to be considered a DUA.

- The protection of groundwater for freshwater aquatic life and for wildlife watering pathways may both be excluded in cases where there is no surface water body (*e.g.*, creek, lake, slough, etc.) within 300 m downgradient of the site. Downgradient is defined as any direction within 45 degrees either side of the direction of groundwater flow.

These exclusions are permitted because they remove pathways that are not applicable based on stable hydrogeological or hydrological features of a site. Accordingly, excluding these pathways allows full protection of human and ecological receptors without any restrictions on the future use of a site.

DRAFT

2.7 Selection of Chemicals of Concern

The chemicals of concern addressed by the guidelines are non-polar hydrocarbon compounds and include the following:

- benzene;
- toluene;
- ethylbenzene;
- xylenes;
- Petroleum Hydrocarbon (PHC) Fraction F1 ($C_6 - C_{10}$, excluding benzene, toluene, ethylbenzene, and xylenes (BTEX), as defined by CCME, 2000a);
- PHC Fraction F2 ($C_{>10} - C_{16}$, as defined by CCME, 2000a);
- PHC Fraction F3 ($C_{>16} - C_{34}$, as defined by CCME, 2000a);
- PHC Fraction F4 ($C_{>34}$, as defined by CCME, 2000a); and,
- carcinogenic polycyclic aromatic hydrocarbons (PAHs), quantified as equivalent benzo(a)pyrene (B(a)P).

Note that carcinogenic PAHs are not included in the definitions of PHC fractions F1 to F4. Analysis for carcinogenic PAHs may or may not be required, but if so, concentrations of PAHs are not subtracted from concentrations of F3, as discussed in the following Section.

2.7.1 Determining Whether PAH Analysis is Required

Analysis for carcinogenic PAHs is required at sites where there is a reasonable expectation that such contamination may be an issue. Two main factors are considered in determining whether analysis for carcinogenic PAHs is required:

- ***Presence of Human Receptors*** – the cancer endpoint is only considered for humans. If the land use is natural area, only ecological pathways plus the protection of potable groundwater are considered. Since the non carcinogenic effects of these PAHs are included in fraction F3, and no guideline is calculated for the protection of potable groundwater for carcinogenic PAHs, it follows that there is no requirement for PAH analysis at upstream oil and gas sites in natural area land use.
- ***Hydrocarbon Type*** – lighter hydrocarbons, such as gasoline, condensate, and petroleum solvents will not generally include significant PAHs (EC, 1992). Heavier hydrocarbons including crude oil, fuel oil, diesel, and waste oil, and unknown hydrocarbon mixtures may contain PAHs (EC, 1992).

Professional judgement should be exercised to determine whether PAH analysis is required at a particular site. The hydrocarbon type should be taken into account together with the type of facility. Examples of upstream facilities or parts of facilities where PAH contamination could be expected include, but are not limited to flare pits, wax pits, soil subjected to flare stack carry-over, fire training areas, floor drains, sumps, tank bottom sludges, process sludges, landfills, and drilling sumps where diesel-based mud was used.

DRAFT

Once the likelihood of PAH contamination has been estimated, and if the land use is agricultural, residential, commercial, or industrial, one of the following three possibilities for PAH characterization should be selected:

1. Carcinogenic PAHs are expected to be present at a site and sufficient analyses are performed to characterize their nature and extent.
2. One or more sources of hydrocarbon that may contain carcinogenic PAHs are present at a site. One worst case sample is analyzed from each source region. If carcinogenic PAHs are below guideline levels in these samples, no further PAH analysis is required. If carcinogenic PAHs are present above guideline levels, then further delineation of PAHs will be required.
3. The source(s) of hydrocarbon contamination is (are) known and do not contain carcinogenic PAHs; in this case no PAH analysis need be undertaken.

When analysis for carcinogenic PAHs is required, the eight compounds to be analyzed are those listed in Table 2.

The definition of the four PHC fractions (CCME, 2000a) specifically excludes carcinogenic PAHs. However, for the Alberta hydrocarbon guidelines there is no provision to subtract the concentrations of carcinogenic PAHs (if measured) from the concentrations of PHC fractions. The reasons for this are two-fold: 1) in general, carcinogenic PAHs will form a small fraction of the overall mass of PHC in a sample, and subtracting them will make negligible difference to the concentration of the PHC fractions; and, 2) subtracting PAHs from F3 would only apply to human health pathways, and so the concentrations of the PHC fractions to be used would depend on whether a human health or ecological

pathway was limiting for that chemical. Such an approach would be difficult to manage and confusing, and is not used.

2.7.2 Expressing PAHs as Equivalent B(a)P Concentration

It would be unnecessarily cumbersome to apply separate guidelines for each of the carcinogenic PAHs listed in Table 2. The guidelines adopt a standard approach (*e.g.*, BCMELP, 1988; USEPA, 1993) in that the carcinogenic potency of each compound is expressed relative to B(a)P. The concentrations of the eight carcinogenic PAHs are reduced to an equivalent concentration of B(a)P by multiplying each by its relative carcinogenic potency and summing:

$$C_{B(a)P} = \sum_i C_i RCP_i$$

Where:

$C_{B(a)P}$ = equivalent concentration of B(a)P (mg/kg);
C_i = concentration of the carcinogenic PAH (mg/kg); and,
RCP_i = relative carcinogenic potency of 'i' carcinogenic PAH (mg/kg, Table 2).

An example of this process is included in the Sample Study Report.

DRAFT

2.8 Subsoil Guidelines

In this project, consistent with the approach taken in CCME (2000a), separate guidelines are provided for surface soils and subsoils. Subsoils are defined as being soils at a depth greater than 1.5 m. The rationale for distinguishing surface soils and subsoils is that: i) some of the direct contact pathways apply only to surface soils; and, ii) for some pathways (*e.g.*, plant/invertebrate soil contact, indoor air inhalation) a less stringent guideline may be appropriate in subsoil to achieve the same level of protection as that achieved in surface soil. However, subsoil guidelines are only applicable as long as subsoil remains at a depth of greater than 1.5 m. This issue is discussed further in Sections 4.1.3 and 5.2.1.

3. SITE ASSESSMENT

3.1 Sampling

The aim of a site assessment program is to adequately characterize the nature (*i.e.*, compounds present) and extent (areal and vertical) of contamination. The BTEX compounds and hydrocarbon fractions F1 and F2 are volatile, and so sampling protocols that minimize the loss of volatile compounds from soil and groundwater samples must be used. Site assessment methodology must follow the protocol set out in:

- *Phase 1 Environmental Site Assessment Guideline for Upstream Oil and Gas Sites.* (AENV 2001c).

In addition, sampling and analysis should follow:

- *Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites. Volumes 1 and 2* (CCME, 1993).

Determination of the dominant soil type is a critical step in determining the appropriate set of guidelines to be used at a site (see Section 2.4). The number of texture measurements required to determine the dominant soil type at a site will depend on the textural complexity of that site as shown in the borehole logs from the site assessment. As a guide, the soil type of at least three samples should be determined from each distinct textural unit at a site. As indicated in Section 2.4, the presence of continuous or extensive lenses of coarse textured material will generally lead to a "coarse" designation for the entire site.

DRAFT

3.2 Analytical Requirements

Chemical analysis may be required for BTEX in soil and water, PHC fractions F1 to F4 in soil, PHC fractions F1 and F2 in water, and PAHs in soil and water.

Analyses should be undertaken by a laboratory accredited by the Canadian Association of Environmental Analytical Laboratories (CAEAL). Certified and accredited methods should be used for BTEX analysis in soil and water. The analytical method for PHC fractions F1 to F4 in soil is defined by CCME (2000c). Analysis of PHC fraction F1 in water should be done using a certified and accredited method for total purgeable hydrocarbons C_6-C_{10}, with the concentration of BTEX compounds subtracted. Analysis of PHC fraction F2 in water should be done using a standard method for total extractable hydrocarbons C_{10}-C_{16}. Analysis of the eight PAHs listed in Table 2 should be done using a certified and accredited method.

Because the CCME Canada-Wide Standard for Petroleum Hydrocarbons in Soil was endorsed by Ministers in May 2001, there has not been sufficient time for all applicant laboratories to be assessed by CAEAL. In the interim, analyses should be directed to CAEAL-accredited laboratories and those that have applied for CAEAL accreditation.

4. USING TIER 1 GUIDELINES

It is anticipated that the majority of sites will be assessed using Tier 1 guidelines. The following Sections explain how the applicable Tier 1 guidelines for a particular site are determined.

4.1 Soil

4.1.1 Applicability of Tier 1 Guidelines

The first decision to be made is whether Tier 1 guidelines are applicable at a site. The assumptions used in the generation of Tier 1 guidelines are conservative, and will be applicable to the majority of sites in Alberta. At sites where the assumptions are not applicable, however, Tier 1 guidelines can not be used, and a Tier 2 or Tier 3 approach must be used. Examples of situations where Tier 1 guidelines would not apply include:

- sites where the soils are predominantly coarse sands and gravels, with bulk hydraulic conductivity greater than 10^{-5} m/s; and,
- sites where the land use does not fall into any of five generic land use scenarios.

4.1.2 Tier 1 Decision Tree

The Tier 1 guidelines for Fine and Coarse surface soil are included in Tables 3 and 4, respectively. The Tier 1 guidelines for Fine and Coarse subsoil are included in Tables 5 and 6, respectively. A five step "Decision Tree" is used to simplify the four tables noted above to the applicable guideline value for each chemical of concern at a site. The Decision Tree is presented in Figure 2. The five steps are as follows:

1. Determine whether subsoil guidelines are applicable at the site. Subsoil guidelines are only applicable at Tier 1 within 15 m of an oilfield wellhead. If subsoil guidelines are not applicable, then surface soil guidelines are used for all soil depths, and the applicable guidelines are found in Tables 3 or 4. If subsoil guidelines are applicable, then they are found in Tables 5 or 6.
2. Identify soil type (Section 2.4). Guidelines for fine soils will be found in Tables 3 and 5 for surface soils and subsoils, respectively. Guidelines for Coarse soils will be found in Tables 4 and 6 for surface soils and subsoils, respectively.
3. Select land use (Section 2.5). Guidelines for each of the five land uses are found in separate blocks of each Table.
4. Exclude any inapplicable pathways (Section 2.6).
5. Select the smallest remaining guideline for each chemical.

DRAFT

Taking as an example a case where subsoil guidelines are not applicable, Step 1 reduces the four possible Tables to two; Step 2 identifies the single Table containing the applicable guidelines for a site; Step 3 identifies the applicable guideline block; Step 4 may reduce the number of pathways in that guideline block, and Step 5 identifies the single guideline applicable to each chemicals of concern at the site.

Once the guideline for each chemical or group has been determined, they can be used to define the extent of contaminated soil at a site. At the majority of sites, the next step will be to remediate any soil contaminated above guideline levels, and then to seek regulatory acceptance. However, at some sites a proponent may wish to consider developing site-specific guidelines at Tier 2 or Tier 3. The proponent would weigh the additional effort of collecting further site data and developing guidelines against possible savings in remedial effort. Tier 2 and 3 approaches are discussed in Sections 5 and 6, respectively.

This Tier 1 soil guideline selection process is illustrated in Case Studies I and II.

4.1.3 Subsoil Guidelines

Subsoil guidelines are summarized in Tables 5 and 6 for Fine and Coarse soils, respectively. Subsoil guidelines are only available at Tier 1 within the 15 m setback from an oilfield wellhead in natural area or agricultural land uses. Subsoil guidelines may be available at Tiers 2B or 3B, once the regulatory framework for these Management Levels is finalized.

4.2 Groundwater

Acceptable levels of chemicals of concern in groundwater are dependant on potential groundwater use. Table 7 provides groundwater guidelines for four potential water uses: human drinking water, freshwater aquatic life, livestock watering, and wildlife watering. Note that two sets of groundwater guidelines are provided for freshwater aquatic life and wildlife watering pathways. One guideline applies to groundwater measurements from monitoring wells located at least [illegible] from a surface water body. The other guideline is for piezometers located within 10 m of a surface water body. Note also that at Fine sites, there is no freshwater aquatic life or wildlife watering guideline for groundwater at least 10 m from the nearest surface water body. This reflects the limited mobility of hydrocarbons in Fine soils.

DRAFT

The groundwater guideline for a [illegible] of the [illegible] for applicable groundwater uses. Applicability is defined as follows:

- The human drinking water guideline is applicable whenever groundwater contamination is present in either i) a domestic use aquifer (DUA), or ii) a groundwater unit hydraulically connected to a DUA. (5 m of saturated Fine-grained material, with a bulk hydraulic conductivity less than 10^{-7} m/s is considered sufficient to ensure isolation between groundwater units). A DUA is defined by Alberta Environment in (AENV, 2001b).
- The livestock watering guideline is applicable whenever the land use is agricultural and on grazing leases within the Green Area.
- The freshwater aquatic life and wildlife watering guidelines are applicable whenever a surface water body is present within 300 m downgradient of the site.

An example of the use of groundwater guidelines is provided in Case Study II.

Note that dilution of groundwater discharging into a moving body of water is not taken into account. This may be considered at Tier 3, with appropriate justification.

If groundwater concentrations at a site exceed guideline values, a proponent has two options:

1. implement a groundwater remediation scheme to reduce hydrocarbon concentrations to below guideline values;
2. consider a Tier 2 or Tier 3 approach.

4.3 Regulatory Acceptance

Two possible scenarios exist for regulatory acceptance at Tier 1:

- If a site assessment shows that soil and groundwater contamination is within applicable Tier 1 guideline levels, a proponent may declare the site uncontaminated and apply for a Reclamation Certificate once surface reclamation work is complete.
- If soil and/or groundwater contamination has been identified at concentrations above applicable Tier 1 guideline levels and subsequently remediated to below those levels then the proponent may declare the site remediated and apply for a Reclamation Certificate once surface reclamation work is complete.

Sites with groundwater contamination beyond applicable guidelines are not eligible for a Reclamation Certificate.

DRAFT

5. SITE SPECIFIC GUIDELINES

Three Management Levels are presently available at Tier 2. These Management Levels are summarized in Table 1. Note that only Tier 2A is presently applicable -- Tiers 2B and 2C are included for discussion only.

- Tier 2A allows for re-calculating Tier 1 guidelines by replacing certain assumed parameters with measured, site-specific values. Examples of such parameters could include soil physical properties and the distance to a nearby surface water body.

- Tier 2B is not currently available, but if implemented would be used where current conditions are protective of human and environmental health, but acknowledgement of certain on-site conditions is required to ensure protection is maintained in the case of future re-development of the site. Examples of such conditions would include i) using subsoil guidelines as remedial objectives (except within the 15 m offset from an oilfield wellhead), and ii) excluding the plant/invertebrate soil contact pathway at graveled or paved sites.

- Tier 2C is not currently available, but when implemented, it will apply to sites where groundwater contamination extends off-site, and temporary land use restrictions are necessary to protect human and ecological health while the groundwater issue is resolved.

These three Management Levels are discussed in more detail below.

5.1 Tier 2A

5.1.1 Introduction

The objective of Tier 2A is to allow limited modifications to Tier 1 so that guidelines which are somewhat customized to a particular site may be generated at a relatively modest level of additional effort.

The following discussion describes how Tier 2A modifications can be made to Tier 1 guidelines. The protocols, equations and non chemical-specific values used to derive the Tier 1 guidelines are available in Volume 1. Tier 1 guideline development is explained, and chemical-specific data are provided in Volume 2. A thorough knowledge of this material will be required in order to derive Tier 2A guidelines. Before proceeding to Tier 2A, a proponent should be clear as to which pathway(s) at a site are limiting at Tier 1. The next step is to determine whether the limiting pathway(s) can be adjusted at Tier 2A. The pathways are divided into three groups:

DRAFT

Pathways that are rarely, if ever, expected to be limiting

- human soil ingestion;
- human soil dermal contact;
- soil ingestion by livestock or wildlife; and,
- protection of groundwater for wildlife watering.

Pathways that may be limiting, but for which no Tier 2A adjustments are permitted

- plant/invertebrate soil contact.

Pathways that may be limiting, and for which Tier 2A adjustments are permitted

- human indoor vapour inhalation;

- Tier 2B is not currently available, but if implemented would be used where current conditions are protective of human and environmental health, but acknowledgement of certain on-site conditions is required to ensure protection is maintained in the case of future re-development of the site. Examples of such conditions would include i) using subsoil guidelines as remedial objectives (except within the 15 m offset from an oilfield wellhead), and ii) excluding the plant/invertebrate soil contact pathway at graveled or paved sites.

- Tier 2C is not currently available, but when implemented, it will apply to sites where groundwater contamination extends off-site, and temporary land use restrictions are necessary to protect human and ecological health while the groundwater issue is resolved.

These three Management Levels are discussed in more detail below.

5.1 Tier 2A

5.1.1 Introduction

The objective of Tier 2A is to allow limited modifications to Tier 1 so that guidelines which are somewhat customized to a particular site may be generated at a relatively modest level of additional effort.

The following discussion describes how Tier 2A modifications can be made to Tier 1 guidelines. The protocols, equations and non chemical-specific values used to derive the Tier 1 guidelines are available in Volume 1. Tier 1 guideline development is explained, and chemical-specific data are provided in Volume 2. A thorough knowledge of this material will be required in order to derive Tier 2A guidelines. Before proceeding to Tier 2A, a proponent should be clear as to which pathway(s) at a site are limiting at Tier 1. The next step is to determine whether the limiting pathway can be adjusted at Tier 2A. The pathways are divided into three groups:

DRAFT

Pathways that are rarely, if ever, expected to be limiting

- human soil ingestion;
- human soil dermal contact;
- soil ingestion by livestock or wildlife;
- protection of groundwater for wildlife watering.

Pathways that may be limiting, but for which no Tier 2A adjustments are permitted

- plant/invertebrate soil contact.

Pathways that may be limiting, and for which Tier 2A adjustments are permitted

- human indoor vapour inhalation;

- protection of potable groundwater; and,
- protection of groundwater for aquatic life or livestock watering.

If one of the pathways in the last group is limiting, then site-specific adjustments can be made to the calculation of the Tier 1 guideline to derive a Tier 2A guideline. The parameters that can be adjusted at Tier 2A are listed and discussed in the following Sections.

Examples of Tier 2A adjustments are provided in Case Study II.

5.1.2 Tier 2A Adjustments

For each of the three pathways noted above for which Tier 2A adjustments are permitted, the parameters that can be adjusted are clearly defined. These are generally the parameters that have the most significant effect on the guideline for that pathway, and are stable parameters (*e.g.*, soil, hydrogeological or meteorological parameters). If a proponent wishes to adjust other parameters, a Tier 3 site-specific risk assessment would be required. The "Tier 2A Parameters" for each pathway are adapted from CCME (2001) and discussed in the following Sections.

5.1.2.1 Human Indoor Vapour Inhalation

The guideline for this pathway is calculated using the equation in Section 3.5 of Volume 2. The Tier 2A Parameters for this pathway are as follows:

Soil Parameters

- total porosity (unitless);
- bulk density (g/cm^3);
- water content (g/g);
- air filled porosity (unitless);
- soil vapour permeability (cm^2).
- organic carbon fraction (g/g); and

Other Parameters

- depth to contamination (m).

DRAFT

The following information should be noted by proponents intending to make a Tier 2A adjustment to the guideline for this pathway:

- Using site-specific values for the first five of the soil parameters listed above is done as a package – either measured, site-specific values are used for all these parameters, or generic values are used for all these parameters.

- The sample must be undisturbed (*e.g.*, collected in a Shelby tube) for all soil parameter measurements except the water content and organic carbon fraction measurements.
- The water content and bulk density measurements must be reported on a dry weight basis.
- Sufficient measurements of soil parameters must be made to adequately characterize the soil(s) at the site. The parameters used in recalculating the guidelines for this pathway should be conservative in relation to the range of values measured at the site.
- The option to input site-specific building parameters is not provided at Tier 2A so that the guidelines generated are protective of humans in any building that might be built on the site.

5.1.2.2 Protection of Potable Groundwater

The guideline for this pathway is calculated using the equation in Section 3.6 of Volume 2. The Tier 2A Parameters for this pathway are as follows:

Soil Parameters

- water content (g/g).

Other Parameters

- recharge rate (m/y);
- hydraulic gradient (unitless);
- saturated hydraulic conductivity of aquifer (m/y); and,
- site length (*i.e.*, length of contaminated material parallel to groundwater flow) (m).

The following information should be noted by proponents intending to [illegible] a Tier 2A adjustment to the guideline for this pathway:

- The water content must be reported on a dry [illegible] basis.
- The local recharge rate may be es[illegible] by [illegible] 2% [illegible]% [illegible]ne or Coarse soil, respectively) of the mean annual precipitation fo[illegible] lo[illegible] m[illegible] gi[illegible] sta[illegible].
- The hydraulic gradient must be re[illegible]sen[illegible]iv[illegible] f c[illegible]itions beneath the contaminated area.
- Saturated hydraulic conductivity is [illegible]s[illegible]red using standard field techniques.
- Sufficient measurements of saturated hydraulic conductivity must be made to be able to estimate the range of this parameter within the aquifer. The value used to calculate the Tier 2A guideline should be conservative, *i.e.*, represent the lower end of the range of measured values.

DRAFT

5.1.2.3 Protection of Groundwater for Aquatic Life or Livestock Watering

The guideline for this pathway is calculated using the equation in Section 4.3 of Volume 2. The Tier 2A Parameters for this pathway are as follows:

Soil Parameters

- total porosity (unitless);
- bulk density (g/cm^3);
- water content (g/g);
- air filled porosity (unitless); and,
- organic carbon fraction (g/g).

Other Parameters

- recharge rate (m/y);
- hydraulic gradient (unitless);
- saturated hydraulic conductivity of aquifer (m/y);
- site length (*i.e.*, length of contaminated material parallel to groundwater flow) (m);
- site width (*i.e.*, width of contaminated material perpendicular to groundwater flow) (m);
- thickness of affected soils (m);
- thickness of unsaturated zone (m);
- distance from top of affected soils to groundwater (m); and,
- distance to nearest surface water (freshwater aquatic life only; m).

The following information should be noted by proponents intending to make a Tier 2A modification to the guideline for this pathway:

- Using site-specific values for the soil parameters listed above is done as a package – either measured, site-specific values are used for all these parameters, or generic values are used for all these parameters.
- The sample must be undisturbed (i.e., collected in a metal tube) for measurements of all soil parameters except the water content and organic carbon measurements.
- The water content and bulk density measurements must be reported on a dry weight basis.
- Sufficient measurements of soil parameters must be made to adequately characterize the soil at the site. The parameters used in recalculating the guidelines for this pathway should be conservative in relation to the range of values measured at the site.
- The local recharge rate may be estimated by taking 2% or 10% (Fine or Coarse soil, respectively) of the mean annual precipitation for a local meteorological station.
- The hydraulic gradient must be representative of conditions beneath the contaminated area.
- Saturated hydraulic conductivity is measured using standard field techniques.

DRAFT

- Sufficient measurements of saturated hydraulic conductivity must be made to be able to estimate the range of this parameter within the aquifer. The value used to calculate the Tier 2A guideline should be conservative, *i.e.*, represent the upper end of the range of measured values.
- The distance downgradient to the nearest receptor for the groundwater protection for *livestock watering* pathway cannot be changed at Tier 2A. (This parameter *can* be adjusted to recalculate the protection of groundwater for *freshwater aquatic life* guideline).

5.1.2.4 Adjusting Hydrocarbon Composition

Tier 1 guidelines are based on an assumed composition of each hydrocarbon fraction (F1 to F4). Details of this assumed composition are included in Volume 1. It is permissible at Tier 2A to re-calculate any of the Tier 1 guidelines except the soil ecological contact guideline, based on the measured composition of each hydrocarbon fraction. (The soil ecological contact pathway is based on measured toxicity data for plants and invertebrates exposed to fractions F1 to F4, and accordingly there is no scope to adjust the hydrocarbon composition for this guideline.) Such a re-calculation requires a determination of the concentration of each hydrocarbon sub-fraction in representative sample(s) of contaminated material. The sub-fractions are defined by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG, 1997). A method for this analysis has been developed by the Atlantic Partners in Risk Based Corrective Action Implementation (Atlantic PIRI, 1999).

5.1.3 Tier 2A Groundwater Guidelines

At Tier 2A, the Tier 1 groundwater guidelines (Table 7) are used with one change. For the groundwater guideline for the protection aquatic life, a site-specific guideline may be calculated based on the actual minimum distance from the dissolved phase plume to the nearest surface water body.

DRAFT

5.1.4 Regulatory Acceptance

Tier 2A guidelines generated by inputting site-specific values for the parameters noted above do not require any engineered or institutional controls in order to provide a similar level of protection for human and ecological receptors to that targeted by Tier 1. Accordingly, Tier 2A guidelines can be used for Unconditional Closure, and a proponent who has remediated a site to accepted Tier 2A guidelines may apply for Reclamation Certificate.

5.2 Tier 2B

Tier 2B is not currently available, as the consultation process with stakeholders is ongoing. An overview of what is being planned for Tier 2B is included to give proponents an idea of what may become available in the future. Tier 2B options would only be available to proponents who had care and control of a site, and so may have limited application at upstream oil and gas sites, where many of

- Sufficient measurements of saturated hydraulic conductivity must be made to be able to estimate the range of this parameter within the aquifer. The value used to calculate the Tier 2A guideline should be conservative, *i.e.,* represent the upper end of the range of measured values.
- The distance downgradient to the nearest receptor for the groundwater protection for *livestock watering* pathway cannot be changed at Tier 2A. (This parameter *can* be adjusted to recalculate the protection of groundwater for *freshwater aquatic life* guideline).

5.1.2.4 Adjusting Hydrocarbon Composition

Tier 1 guidelines are based on an assumed composition of each hydrocarbon fraction (F1 to F4). Details of this assumed composition are included in Volume 1. It is permissible at Tier 2A to re-calculate any of the Tier 1 guidelines except the soil ecological contact guideline, based on the measured composition of each hydrocarbon fraction. (The soil ecological contact pathway is based on measured toxicity data for plants and invertebrates exposed to fractions F1 to F4, and accordingly there is no scope to adjust the hydrocarbon composition for this guideline.) Such a re-calculation requires a determination of the concentration of each hydrocarbon sub-fraction in representative sample(s) of contaminated material. The sub-fractions are defined by the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG, 1997). A method for this analysis has been developed by the Atlantic Partners in Risk Based Corrective Action Implementation (Atlantic PIRI, 1999).

5.1.3 Tier 2A Groundwater Guidelines

At Tier 2A, the Tier 1 groundwater guidelines (Table 7) are used with one change. For the groundwater guideline for the protection aquatic life, a site-specific guideline may be calculated based on the actual minimum distance from the dissolved phase plume to the nearest surface water body.

5.1.4 Regulatory Acceptance

Tier 2A guidelines generated by inputting site-specific values for the parameters noted above do not require any engineered or institutional controls in order to provide a similar level of protection for human and ecological receptors to that targeted by Tier 1. Accordingly, Tier 2A guidelines can be used for Unconditional Closure, and a proponent who has remediated a site to accepted Tier 2A guidelines may apply for Reclamation Certificate.

DRAFT

5.2 Tier 2B

Tier 2B is not currently available, as the consultation process with stakeholders is ongoing. An overview of what is being planned for Tier 2B is included to give proponents an idea of what may become available in the future. Tier 2B options would only be available to proponents who had care and control of a site, and so may have limited application at upstream oil and gas sites, where many of

DRAFT

the facilities are on leased land. The remainder of this Section is italicized to emphasize the fact that it is not available at present.

Tier 2B is applicable in 2 situations, as described in the two following Sections.

5.2.1 Subsoil Guidelines

Subsoil guidelines are presented in Tables 5 and 6 for Fine and Coarse soil, respectively. Subsoil guidelines are only protective while subsoil remains at depths greater than 1.5 m. The use of subsoil guidelines within the 15 m offset in natural areas or agricultural land use is available at Tier 1 and was discussed in Section 4.1.3. In all other situations, passive on-site management (i.e., ensuring that subsoil is not disturbed) will be required if subsoil guidelines are included in the remediation objectives for a site.

If subsoil guidelines are used at a site, a record of this situation is required to ensure that future developers of the site are aware of the situation

5.2.2 Ecological Soil Contact Pathway Suspended at Paved or Gravelled Sites

It is common practice for parts of certain upstream facilities (e.g., gas plants) to be paved or graveled. Plant growth in these areas is often not required or actively discouraged to control fire hazard. At such sites, there is no requirement for the soil to support an ecological function, and accordingly the surface soil plant/invertebrate soil contact pathway can be suspended. It should be noted, however, that in such cases the subsoil plant/invertebrate soil contact pathway would be applicable to both surface and subsoil, because the guidelines for this pathway include qualitative consideration of other issues, including aesthetics and protection of buried infrastructure.

If the surface soil plant/invertebrate soil contact pathway is suspended at a site, a record of this situation is required to ensure that future developers of the site are aware of the situation..

5.3 Tier 2C

Tier 2C is not currently available, as the regulatory and scientific basis for its application are still being developed. An overview of what is being planned for Tier 2C is included to give proponents an idea of what may become available in the future. The remainder of this Section is italicized to emphasize the fact that it is not available at present.

Tier 2C is anticipated to apply at a site where contaminated soil has generated an off-site groundwater plume with hydrocarbon concentrations above Tier 1 groundwater guidelines.

DRAFT

Remediation of soil contamination to Unconditional Closure guidelines will normally be required. In many cases, natural attenuation of the dissolved hydrocarbon plume will reduce concentrations in groundwater below applicable guidelines within a reasonable time. Provisions are required to ensure that human and ecological exposure is eliminated (e.g., by prohibiting groundwater usage within the plume area) until groundwater concentrations are compliant.

5.3.1 Requirements

The requirements for a site to be considered for Conditional Closure under the Groundwater Plume Scenario are as follows:

Sources *- contaminant sources, including soils contaminated above Unconditional Closure guidelines and any free product, have been remediated or removed.*

Groundwater *– Tier 2C Closure would apply to sites with concentrations of hydrocarbons in groundwater above applicable guidelines.*

Plume Stability *– the proponent must demonstrate that the Groundwater Plume (defined as the areal extent of groundwater contaminated above applicable guidelines) is stable or shrinking.*

Expectation of Attenuation *– the proponent must demonstrate that that there is a reasonable expectation that the groundwater plume will attenuate naturally to the point where contaminant concentrations in groundwater fall below unconditional guidelines within a reasonable period of time (normally 10 years).*

Salinity Requirement *- groundwater salinity is below 4,000 ppm of total dissolved solids (TDS).*

Required Controls *- appropriate controls, negotiated between all stakeholders, are in place to ensure that no receptors have access to groundwater from within the Groundwater Plume during the period of Conditional Closure; this restriction implies that no groundwater wells can be installed or dugouts excavated in this area, and any existing wells or dugouts cannot be used for the duration of the Conditional Closure.*

Closure Piezometers *– the proponent must identify an appropriate number of piezometers ("Closure Piezometers") that are representative of the highest groundwater concentrations at the site. These piezometers will be used to determine when groundwater concentrations have decreased to within applicable guideline values, and hence when Unconditional Closure has been achieved and a letter of compliance can be issued. It is anticipated that at small, simple, well-characterized sites, a single Closure Piezometer located close to the source on the main plume axis will be sufficient. Larger or more complex sites will require more Closure Piezometers.*

DRAFT

5.3.2 Regulatory Acceptance

If the conditions noted in Section 5.3.1 above are met at a site, the proponent can apply to AENV for a Management Plan Acceptance Letter. If the application is successful, and the landowner agrees to the plan, then the period of Conditional Closure can begin. There is no requirement for ongoing groundwater monitoring during Conditional Closure, as the plume has already been demonstrated to be stable or shrinking, and controls are in place to restrict human or ecological exposure to contaminated groundwater.

Confirmatory sampling to demonstrate that groundwater concentrations have reduced to below applicable guideline values must be conducted within 10 years, unless another time frame is agreed between all stakeholders. Confirmatory sampling will involve three groundwater sampling events. Three sets of samples will be analyzed from each Closure Piezometer, for all parameters that were previously present above guideline levels. The three sampling events shall be completed intervals of approximately six months, to allow an assessment of seasonal variability. If the hydrocarbon concentrations in all three samples are below applicable guidelines, the site is eligible for Unconditional Closure.

6. SITE-SPECIFIC (TIER 3) REMEDIATION OBJECTIVES

There may be sites where the amount of flexibility available under Tier 1 or Tier 2 is insufficient to adequately represent the complexity of processes occurring and pathways to be considered. In such cases a proponent may elect to develop Tier 3 site-specific remediation objectives. In deciding to proceed to Tier 3, a proponent will evaluate the additional required site assessment and site-specific risk assessment work against savings from a possible relaxation of Tier 1 or Tier 2 guideline values. At Tier 3, a proponent has the flexibility to use a wide range of approaches to represent site-specific conditions and processes. However the proponent is required to provide a rigorous scientific justification for any methodology used.

At Tier 3, the same high level of protection for humans and ecological receptors is required as at Tiers 1 and 2. Three Management Levels are distinguished at Tier 3, analogous to the three Management Levels available at Tier 2. Note that Tier 3B is not currently available, and accordingly is italicized below.

Tier 3A. At Tier 3A, more detailed site-specific information, which could include site-specific toxicity information, and/or the use of different models, are used to develop site-specific remediation objectives (SSROs). The protection of human and ecological receptors is achieved without the need for engineered or institutional controls. The same environmental protection goals used at Tier 1 apply. All pathways and receptors considered at Tier 1 must be included as well as any that are important and particular to the site under consideration.

Tier 3B. ***Tier 3B is similar to Tier 3A, but including one or more of the issues discussed under Tier 2B. Tier 3B can be used to address situations where on-site contamination is present above Tier 1 levels, but human and ecological health are protected so long as certain passive management practices remain in place, such as leaving the site paved, or leaving subsoil undisturbed. At Tier 3B, successful remedial efforts can be acknowledged by a Letter of Compliance (On-Site Management). This option is not available at present.***

Tier 3C. In Tier 3C risk assessments, the protection of human and ecological receptors is achieved partly through the use of engineered or institutional controls. Tier 3C risk assessments are not eligible for a Reclamation Certificate.

Providing detailed guidance for site-specific risk assessment is outside the scope of this project. Much provincial and federal guidance is available on this subject, but this material will be familiar to risk assessment professionals and is not repeated here.

DRAFT

DRAFT

5.3.2 Regulatory Acceptance

If the conditions noted in Section 5.3.1 above are met at a site, the proponent can apply to AENV for a Management Plan Acceptance Letter. If the application is successful, and the landowner agrees to the plan, then the period of Conditional Closure can begin. There is no requirement for ongoing groundwater monitoring during Conditional Closure, as the plume has already been demonstrated to be stable or shrinking, and controls are in place to restrict human or ecological exposure to contaminated groundwater.

Confirmatory sampling to demonstrate that groundwater concentrations have reduced to below applicable guideline values must be conducted within 10 years, unless another time frame is agreed between all stakeholders. Confirmatory sampling will involve three groundwater sampling events. Three sets of samples will be analyzed from each Closure Piezometer, for all parameters that were previously present above guideline levels. The three sampling events shall be completed intervals of approximately six months, to allow an assessment of seasonal variability. If the hydrocarbon concentrations in all three samples are below applicable guidelines, the site is eligible for Unconditional Closure.

6. SITE-SPECIFIC (TIER 3) REMEDIATION OBJECTIVES

There may be sites where the amount of flexibility available under Tier 1 or Tier 2 is insufficient to adequately represent the complexity of processes occurring and pathways to be considered. In such cases a proponent may elect to develop Tier 3 site-specific remediation objectives. In deciding to proceed to Tier 3, a proponent will evaluate the additional required site assessment and site-specific risk assessment work against savings from a possible relaxation of Tier 1 or Tier 2 guideline values. At Tier 3, a proponent has the flexibility to use a wide range of approaches to represent site-specific conditions and processes. However the proponent is required to provide a rigorous scientific justification for any methodology used.

At Tier 3, the same high level of protection for humans and ecological receptors is required as at Tiers 1 and 2. Three Management Levels are distinguished at Tier 3, analogous to the three Management Levels available at Tier 2. Note that Tier 3B is not currently available, and accordingly is italicized below.

Tier 3A. At Tier 3A, more detailed site-specific information, which could include site-specific toxicity information, and/or the use of different models, are used to develop site-specific remediation objectives (SSROs). The protection of human and ecological receptors is achieved without the need for engineered or institutional controls. The same environmental protection goals used at Tier 1 apply. All pathways and receptors considered at Tier 1 must be included as well as any that are important and particular to the site under consideration.

Tier 3B. Tier 3B is similar to Tier 3A, but including one or more of the issues discussed under Tier 2B. Tier 3B can be used to address situations where on-site contamination is present above Tier 1 levels, but human and ecological health are protected so long as certain passive management practices remain in place, such as leaving the site paved, or leaving subsoil undisturbed. At Tier 3B, successful remedial efforts can be acknowledged by a Letter of Compliance (On-Site Management). This option is not available at present.

Tier 3C. In Tier 3C risk assessments, the protection of human and ecological receptors is achieved partly through the use of engineered or institutional controls. Tier 3C risk assessments are not eligible for a Reclamation Certificate.

Providing detailed guidance for site-specific risk assessments is outside the scope of this project. Much provincial and federal guidance is available on this subject, but this material will be familiar to risk assessment professionals and is not treated here.

DRAFT

7. REFERENCES

AENV (Alberta Environment), 1995. Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update. C&R/IL/95-3. April, 1995.

AENV (Alberta Environment), 2000a. A Proposed Management Framework for Reclamation and Remediation of Oil and Gas Exploration and Production Sites in Alberta. Environmental Sciences Division, Environmental Service. 4 January 2000.

AENV (Alberta Environment), 2000b. Guideline for Management of Risks at Contaminated Sites in Alberta (*draft*). Environmental Sciences Division, Environmental Service. May 2000.

AENV (Alberta Environment), 2001a. Salt Contamination Assessment and Remediation Guidelines. Pub. No. T/606. May, 2001.

AENV(Alberta Environment), 2001b Alberta Groundwater Quality Objectives (*in preparation*).

AENV(Alberta Environment), 2001c Phase 1 Environmental Site Assessment Guideline for Upstream Oil and Gas Sites. Report # ESD/LM/01-1. Pub. No. T/573. April, 2001.

Atlantic PIRI (Partners in RBCA Implementation) 1999. Guidelines for Laboratories, Tier 1 and Tier 2 Petroleum Hydrocarbon Methods. Draft Version 1.0. December 1999. Available at: http://www.atlanticrbca.com/

BCMELP (British Columbia Ministry of Environment, Lands and Parks), 1988. Special Waste Regulation. Waste Management Act. BC Reg. 63/88. Deposited February 18, 1988. Effective April 1, 1988.

CCME (Canadian Council of Ministers of the Environment), 1993. Guidance Manual on Sampling, Analysis, and Data Management for Contaminated Sites. Volumes 1 and 2. CCME-EPC-NCS62E/NCS66E.

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines.

CCME (Canadian Council of Ministers of the Environment), 2001 Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil. Soil Quality Guidance. April 2001.

CCME (Canadian Council of Ministers of the Environment), 2000a. Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil. Scientific Rationale. Supporting Technical Document. December, 2000.

CCME (Canadian Council of Ministers of the Environment), 2000c, Analysis of Petroleum Hydrocarbons in Soil – CCME Tier 1 Method (*under revision*).

EC (Environment Canada), 1992. Tabs on Contaminated Sites - Tab #5: Sampling and Analysis of Hydrocarbon Contaminated Groundwater. Contaminated Sites Program – Federal Sites. March 1992.

EUB (Alberta Energy and Utilities Board), 1996. Advisory Land Use Planning Notes, Abandoned Oil and Gas Wells (Draft). October 1996.

DRAFT

EUB (Alberta Energy and Utilities Board), 1999. EUB Minimum Setback Recommendations, An Overview. March 1999.

TPHCWG (Total Petroleum Hydrocarbon Criteria Working Group), 1997. Total Petroleum Hydrocarbon Criteria Working Group Series (4 Volumes).

US EPA (U.S. Environmental Protection Agency), 1993. Provisional guidance for quantitative risk assessment of polycyclic aromatic hydrocarbons. Environmental Criteria and Assessment Office. Cincinnati, OH, Office of Health and Environmental Assessment.

DRAFT

Table 1. Management Levels

Management Level [1]	*Summary*	*Reclamation Certificate?* [2]
Tier 1	Site complies with Tier 1 surface soil guidelines. Subsoil guidelines allowed for soils below 1.5 m only in agricultural land or natural areas and only within 15m setback from wellhead.	YES
Tier 2A	Same as Tier 1, with guidelines recalculated using site-specific values for certain stable parameters (*e.g.*, soil properties, distance to creek, etc.)	YES
Tier 2B	***Acknowledgement of certain on-site conditions is required (e.g., subsoil guidelines used for soils below 1.5 m, except as specified in Tier 1 above, or ecological soil contact pathway suspended at paved or graveled sites) - NOT PRESENTLY AVAILABLE (JUNE 2001)***	***TBD***
Tier 2C	***Off-Site Management, requiring 3rd party landowner buy-in (e.g., off-site groundwater plume being managed by natural attenuation) - NOT PRESENTLY AVAILABLE (JUNE 2001)***	***NO***
Tier 3A	Site-specific risk assessment requiring no land use restrictions (*e.g.*, remediation objectives calculated based on site-specific toxicity testing or models other than those used at Tier 1).	YES
Tier 3B	***Same as Tier 3A, with acknowledgement of certain on-site conditions required as in Tier 2B - NOT PRESENTLY AVAILABLE (JUNE 2001)***	***TBD***
Tier 3C	Site-specific risk assessment/risk management requiring engineered or institutional controls to manage off-site contamination.	NO

Greyed-out entries are not presently applicable

DRAFT

Notes:

1. *Further details for all Management Levels available in appropriate sections of text.*
2. *A "yes" in this column implies that remediation to this management level is compatible with the issuance of a reclamation certificate. All the normal requirements for a reclamation certificate must still be met.*

TBD = to be determined

Table 1. Management Levels

Management Level[1]	*Summary*	*Reclamation Certificate?*[2]
Tier 1	Site complies with Tier 1 surface soil guidelines. Subsoil guidelines allowed for soils below 1.5 m only in agricultural land or natural areas and only within 15m setback from wellhead.	YES
Tier 2A	Same as Tier 1, with guidelines recalculated using site-specific values for certain stable parameters (*e.g.*, soil properties, distance to creek, etc.)	YES
Tier 2B	Acknowledgment of off-site impacts; remediation to Tier 1 guidelines at property boundary for soils below 1.5 m; exceptions to Tier 1 guidelines allowed at property boundary if NOT PRESENTLY AVAILABLE	TBD
Tier 2C	Off-Site Management Program; Tier 1 guidelines must be met at property boundary for soils below 1.5 m, as for Tier 1 (see Table 2, Note 2)	NO
Tier 3A	Site-specific risk assessment requiring no land use restrictions (*e.g.*, remediation objectives calculated based on site-specific toxicity testing or models other than those used at Tier 1).	YES
Tier 3B	Same as Tier 3A, with acknowledgment of off-site impacts; remediation to Tier 2B NOT PRESENTLY AVAILABLE (draft 2004)	TBD
Tier 3C	Site-specific risk assessment/risk management requiring engineered or institutional controls to manage off-site contamination.	NO

Grayed-out entries are not presently applicable

DRAFT

Notes:

1. *Further details for all Management Levels available in appropriate Protocol document.*
2. *A "yes" in this column implies that remediation to this management level is compatible with the issuance of a reclamation certificate. All the normal requirements for a reclamation certificate must still be met.*

TBD = to be determined

Table 2. Relative Carcinogenic Potency Factors for PAH Compounds

PAH Compound	*Relative Carcinogenic Potency*
Benzo[a]pyrene	1 [1]
Benzo[a]anthracene	0.1 [1]
Benzo[b]fluoranthene	0.1 [1]
Benzo[j]fluoranthene	0.1 [2]
Benzo[k]fluoranthene	0.1 [1]
Chrysene	0.0044 [3]
Dibenzo[a,h]anthracene	1.1 [1]
Indeno[1,2,3-cd]pyrene	0.2 [1]

Notes:

1. *BCMELP (1988);*
2. *assumed, based on value for B[k]F; and,*
3. *USEPA (1993).*

DRAFT

Table 3. Alberta Tier 1 Hydrocarbon Guidelines for Fine Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	**260**	**900**	**800**	**5,600**
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	**4.3**	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [1]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) [1]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	450	1,200	F3	**260**	**900**	**800**	5,600
	Soil Ingestion (Livestock)	33	1,800	1,200	4,900	F3	4,000	3,700	6,000	**4,000**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Residential	Human Soil Ingestion	1,200	22,000	10,000	RES		15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES		RES	RES	RES	RES
	Human Vapour Inhalation (basement)	1.9	4,600	2,000	50	N	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)	1.9	4,600	2,000	50	N	940	5,200	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	2	N	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	14	300	60	,20	F	**260**	**900**	**800**	**5,600**
	Protection of Groundwater for Aquatic Life *	RES	RES	ES	RE	F	TBD	TBD	NA	NA
Commercial	Human Soil Ingestion	4,400	S	RES	RE	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	S	RES	RE	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22	00	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	**0.07**	**.8**	**0**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	0	690	1,500	F3	**660**	**1,500**	**2,500**	**6,600**
	Protection of Groundwater for Aquatic Life *	RES	S	RES	RES	F3	TBD	TBD	NA	NA
Industrial	Human Soil Ingestion	4,400	RES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	16	RES	RES	RES	RES
	Human Vapour Inhalation	9	22,000	9,700	2,400	NA	4,600	25,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	38	450	690	1,500	F3	**660**	**1,500**	**2,500**	**6,600**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA

DRAFT

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of this document.

Notes:

1. this pathway can be excluded within 15 m of an oilfield wellhead;

***bold** = lowest value for each chemical and land use;*

underlined = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife pathways may not apply at a given site: see text for details;*

BaP = benzo(a)pyrene;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined;

F3 = ecological endpoints for B(a)P are included in the guideline for F3; and,

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 4. Alberta Tier 1 Hydrocarbon Guidelines for Coarse Surface Soil

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	**130**	450	**400**	**2,800**
	Soil Ingestion (Wildlife)	93	5,200	3,400	14,000	F3	11,000	10,000	17,000	11,000
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
Agricultural	Human Soil Ingestion	1,200	22,000	10,000	RES	4.9	15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES	**4.3**	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [1]	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) [1]	**0.048**	120	54	**14**	NA	**30**	**150**	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	90	F3	**130**	450	**400**	**2,800**
	Soil Ingestion (Livestock)	33	1,800	1,200	4,900	F3	4,000	3,700	6,000	4,000
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Livestock	2.2	2,200	16,000	25,000	F3	11,000	8,600	NA	NA
Residential	Human Soil Ingestion	1,200	22,000	10,000	RES		15,000	8,000	18,000	25,000
	Human Dermal Contact	2,700	RES	RES	RES		RES	RES	RES	RES
	Human Vapour Inhalation (basement)	0.077	200	88	2	N	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade)	**0.048**	120	54	1	N	**30**	**150**	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	**0.36**	4	N	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	8.3	24	91	9	F	130	450	**400**	**2,800**
	Protection of Groundwater for Aquatic Life *	1.6	**0.1**	79	5	F	360	230	NA	NA
Commercial	Human Soil Ingestion	4,400	S	ES	RE	18	RES	29,000	RES	RES
	Human Dermal Contact	9,700	S	RES	E	**16**	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1	630	160	NA	**310**	1,700	NA	NA
	Protection of Potable Groundwater *	**0.13**	.6	0	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13			130	F3	330	760	**1,700**	**3,300**
	Protection of Groundwater for Aquatic Life *	1.6	0.1	79	59	F3	360	**230**	NA	NA
Industrial	Human Soil Ingestion	4,400	ES	RES	RES	18	RES	RES	RES	RES
	Human Dermal Contact	9,700	RES	RES	RES	**16**	RES	RES	RES	RES
	Human Vapour Inhalation	0.55	1,400	630	160	NA	**310**	1,700	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	13	71	200	130	F3	330	760	**1,700**	**3,300**
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA

DRAFT

Guidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of this document.

Notes:

1. this pathway can be excluded within 15 m of an oilfield wellhead;
***bold** = lowest value for each chemical and land use;*
underlined = PHC guidelines adopted without change from CCME (2000);
** the potable groundwater, aquatic life, and groundwater for wildlife pathways may not apply at a given site: see text for details;*
BaP = benzo(a)pyrene;

all values are presented to two significant figures
RES = calculated value exceeds 30,000 mg/kg;
NA = not applicable;
TBD = to be determined; and,
F3 = ecological endpoints for B(a)P are included in the guideline for F3; and,
F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 5. Alberta Hydrocarbon Guidelines for Fine Subsoil
*Applicable below 1.5 m depth within 15 m radius of wellhead**

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area [1]	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3,	**750**	**2,200**	**3,500**	**10,000**
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Wildlife *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Agricultural [1]	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [2]	1.9	4,600	2,000	500	NA	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade) [2]	1.9	4,800	2,100	520	NA	990	5,500	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	300	450	1,200	F3	**750**	**2,200**	**3,500**	**10,000**
	Soil Ingestion (Livestock)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
	Protection of Groundwater for Livestock	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Residential	Human Soil Ingestion	NA	NA	NA	N	N	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	N	N	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	1.9	4,600	000	50	N	940	5,200	NA	NA
	Human Vapour Inhalation (slab-on-grade)	1.9	4,800	00	52	N	990	5,500	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.8**	**0.1**	**2**	N	1,900	2,600	NA	NA
	Soil Contact (Plants and Invertebrates)	28	00	50	20	F3	**750**	**2,200**	**3,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	RES	S	RES	RE	F3	TBD	TBD	NA	NA
Commercial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	A	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	**0.07**	**0.86**	**0.19**	**25**	NA	1,900	**2,600**	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	**1,000**	3,000	**5,000**	**10,000**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA
Industrial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	9	23,000	9,800	2,500	NA	4,800	26,000	NA	NA
	Protection of Potable Groundwater *	**0.073**	**0.86**	**0.19**	**25**	NA	1,900	**2,600**	NA	NA
	Soil Contact (Plants and Invertebrates)	77	450	690	1,500	F3	**1,000**	3,000	**5,000**	**10,000**
	Protection of Groundwater for Aquatic Life *	RES	RES	RES	RES	F3	TBD	TBD	NA	NA

DRAFT

uidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of this document.

otes: 1. subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. this pathway can be excluded within 15 m of an oilfield wellhead;

***bold** = lowest value for each chemical and land use;*

underlined = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife; pathways may not apply at a given site: see text for details;*

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and,

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

Table 6. Alberta Hydrocarbon Guidelines for Coarse Subsoil
Applicable below 1.5 m depth within 15 m radius of wellhead

Land Use	Exposure Pathway	Benzene (mg/kg)	Toluene (mg/kg)	Ethyl-benzene (mg/kg)	Xylenes (mg/kg)	B(a)P (mg/kg)	F1 (mg/kg)	F2 (mg/kg)	F3 (mg/kg)	F4 (mg/kg)
Natural Area [1]	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	**350**	1,500	**2,500**	**10,000**
	Soil Ingestion (Wildlife)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Wildlife *	5.3	5,400	RES	RES	F3	16,000	15,000	NA	NA
Agricultural [1]	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation (basement) [2]	0.077	200	88	22	NA	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade) [2]	**0.054**	140	61	**15**	NA	**40**	**190**	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	48	180	180	F3	**350**	1,500	**2,500**	**10,000**
	Soil Ingestion (Livestock)	NA	NA	NA	NA	F3	NA	NA	NA	NA
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
	Protection of Groundwater for Livestock	2.2	2,200	16,000	25,000	F3	11,000	8,600	NA	NA
Residential	Human Soil Ingestion	NA	NA	NA	N	N	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	N	N	RES	RES	RES	RES
	Human Vapour Inhalation (basement)	0.077	200	88	2	N	50	240	NA	NA
	Human Vapour Inhalation (slab-on-grade)	**0.054**	140	61	1	N	**40**	**190**	NA	NA
	Protection of Potable Groundwater *	0.13	1.6	0.3	4	N	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	17	8	180	18	F3	350	1,500	**2,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	1.6	0.1	79	5	F3	360	230	NA	NA
Commercial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	**340**	1,800	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	**3,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA
Industrial	Human Soil Ingestion	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Dermal Contact	NA	NA	NA	NA	NA	RES	RES	RES	RES
	Human Vapour Inhalation	0.58	1,500	660	170	NA	**340**	1,800	NA	NA
	Protection of Potable Groundwater *	**0.13**	1.6	**0.36**	**49**	NA	3,700	5,100	NA	NA
	Soil Contact (Plants and Invertebrates)	25	140	390	260	F3	700	2,000	**3,500**	**10,000**
	Protection of Groundwater for Aquatic Life *	1.6	**0.16**	79	59	F3	360	**230**	NA	NA

DRAFT

uidelines apply for all substances. Pathways apply as per Sections 2.6, 4 and 5 of this document.

otes: 1. subsoil guidelines are available at Tier 1 within 15 m of wellhead in natural area and agricultural; otherwise Tier 2B management is required.

2. this pathway can be excluded within 15 m of an oilfield wellhead;

***bold** = lowest value for each chemical and land use;*

<u>underlined</u> = PHC guidelines adopted without change from CCME (2000);

** the potable groundwater, aquatic life, and groundwater for wildlife;*

pathways may not apply at a given site: see text for details;

all values are presented to two significant figures

RES = calculated value exceeds 30,000 mg/kg;

NA = not applicable;

TBD = to be determined; and

BaP = benzo(a)pyrene

F3 = ecological endpoints for B(a)P are included in F3; and,

F1 to F4 = petroleum hydrocarbon fractions defined by CCME (2000c)

F1 to F4 = petroleum hydrocarbon fractions as defined by CCME (2000).

Table 7. Alberta Hydrocarbon Guidelines for Groundwater

Criteria	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)	B(a)P (mg/L)	F1 (mg/L)	F2 (mg/L)
All Soils							
Human Drinking Water	0.005	0.024	0.0024	0.3	0.00001	4.6	2.1
Livestock Watering	0.51	29	19	76	NA	62	57
All Soils; Piezometers <10 m from Surface Water Body							
Freshwater Aquatic Life	0.370	0.002	0.090	0.180	NA	ND	ND
Wildlife Watering	1.2	69	45	180	NA	150	140
Coarse Soils; Piezometers >10 m from Surface Water Body							
Freshwater Aquatic Life	0.53	0.021	4.8		NA	NG	NG
Wildlife Watering	1.8	NG	NG		NA	NG	NG
Fine Soils; Piezometers >10 m from Surface Water Body							
Freshwater Aquatic Life	NG	NG	NG		NA	NG	NG
Wildlife Watering	NG	NG	NG	NG	NA	NG	NG

DRAFT

Notes:
NG = no guideline required for this pathway – limited by solubility from ever exceeding surface water criteria at the mixing set;
NA = not applicable;
ND = not determined, due to uncertainties with the critical body residue method for determining chronic toxicity; and,
see Volume 2 of this project for further explanation of values in this Table.

FIGURE 1. REGULATORY PROCESS FOR TIER 1, TIER 2, AND TIER 3 GUIDELINES
(Adapted from AENV, 2000b)

DRAFT

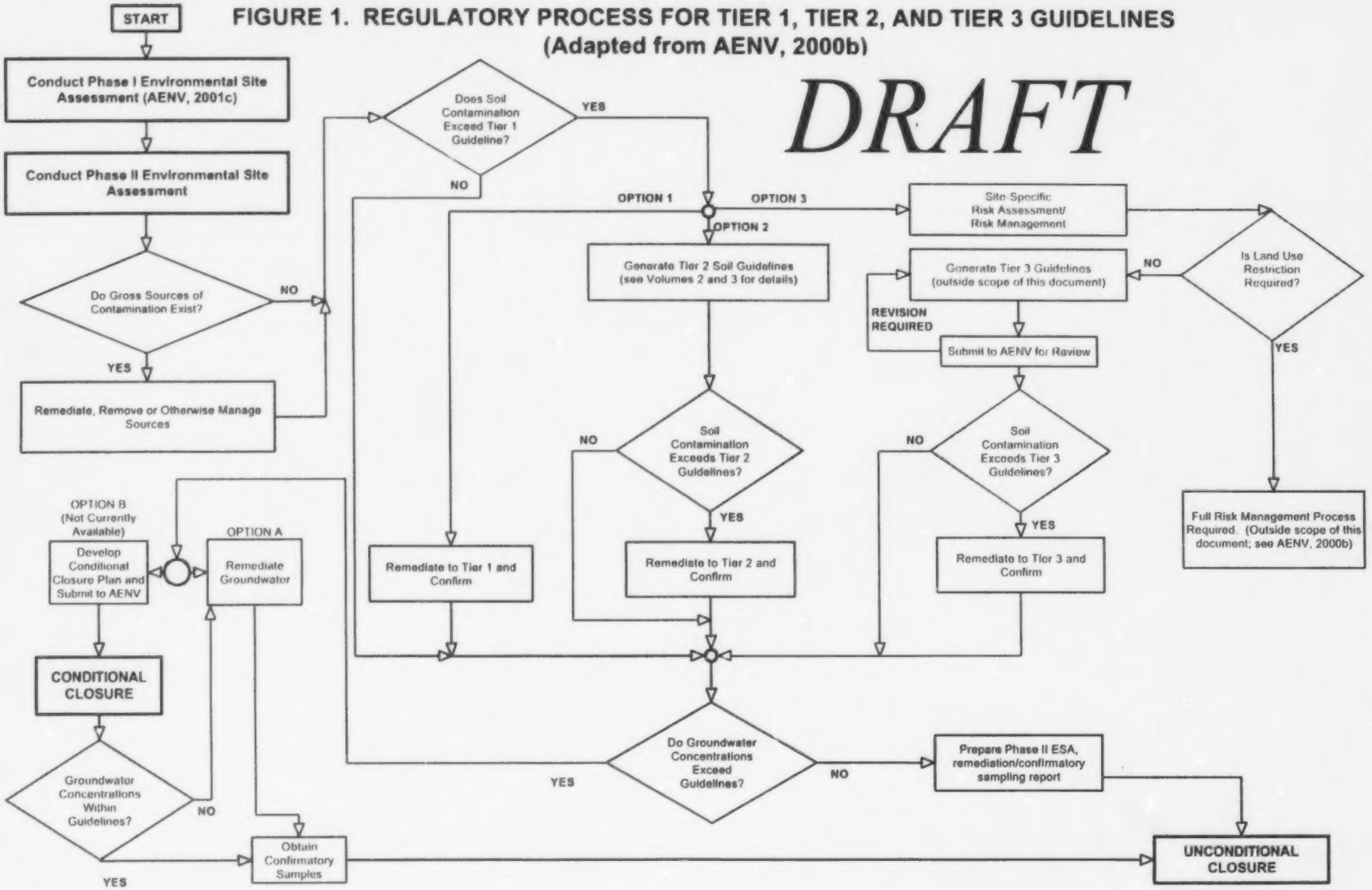
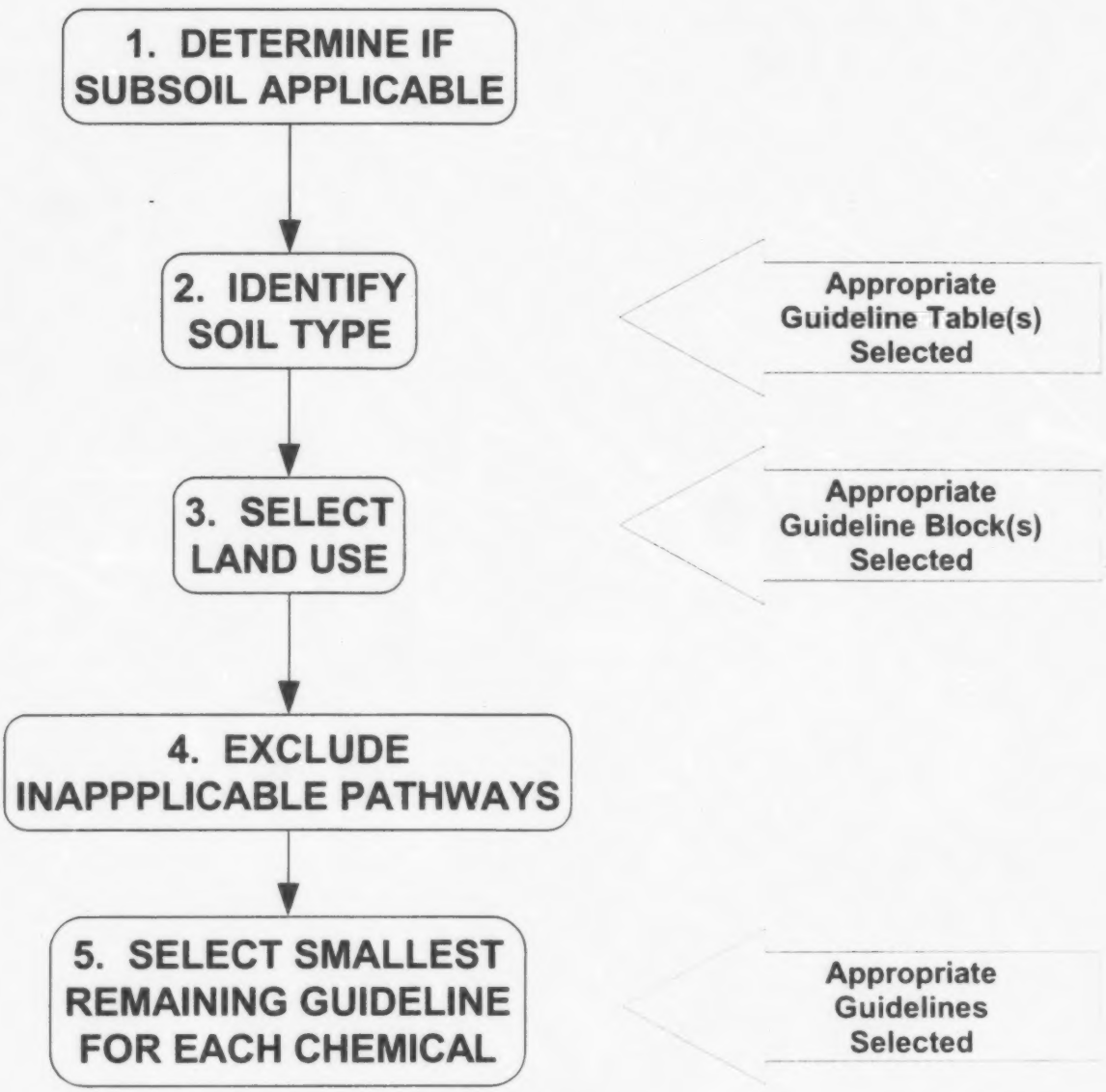


FIGURE 2. DECISION TREE FOR TIER 1 SOIL GUIDELINE SELECTION

DRAFT


1. DETERMINE IF SUBSOIL APPLICABLE
2. IDENTIFY SOIL TYPE
Appropriate Guideline Table(s) Selected
3. SELECT LAND USE
Appropriate Guideline Block(s) Selected
4. EXCLUDE INAPPPLICABLE PATHWAYS
5. SELECT SMALLEST REMAINING GUIDELINE FOR EACH CHEMICAL
Appropriate Guidelines Selected